NATIONAL BUREAU OF STANDARDS REPORT

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LEGIBILITY, ESTHETICS, AND PAGE SIZE

Technical Report

to

National Archives and Records Service
General Services Administration
Washington, D. C.

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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Gerald L. Howett
Sensory Environment Section
Building Environment Division
Center for Building Techn dogy

Technical Report
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Prepared

by

Gerald L. Howett, Research Psychologist

Sensory Environment Section

Reviewed by:

P. R. Achenbach

P. R. Achenbach, Acting Chief
Sensory Environment Section

S. Kramer

S. Kramer, Federal Building Research
Program Coordinator, CBT

R. N. Wright

R. N. Wright, Acting Deputy Director
(Technical), CBT

Approved by:

P. R. Achenbach

P. R. Achenbach, Chief
Building Environment Division
Center for Building Technology
Institute for Applied Technology
National Bureau of Standards

FOREWORD

This report is part of an overall study of the sizes of paper used in communications, sponsored jointly by the National Archives and Records Service of the General Services Administration, and the National Bureau of Standards. The coordinator of the NBS contribution to the project was William K. Wilson, Chief of the Paper Evaluation Section of the Product Evaluation Division of the Institute for Applied Technology.

In preliminary discussions of the page-size problem held jointly by the sponsoring agencies, it became clear that some of the variables that would go into determining an optimum choice for the sizes of paper are psychological-behavioral in nature. Some of these variables, particularly those relating to the legibility of various arrangements of the print on the paper, were seen to be of major interest for those concerned with written communication, not only in connection with the specific question of paper size, but in general. Since a direct experimental attack on the legibility problem would have required an investment of time, money, and personnel on a scale that could not be considered, it was decided to limit investigation of these factors to an evaluative survey of the existing literature on the subject.

This report is basically such a survey, with sections added on the esthetics of page design, and some consideration of the interrelations between reading speed, esthetics, and limited aspects of other variables. The report makes no attempt to consider the general problems of paper handling and economic factors, which are clearly key issues in a full analysis of paper sizes, both from the users' and the manufacturers' points of view.

The legibility survey concentrated on "hard" experimental evidence rather than on intuitive speculations. The literature of typography-reading-legibility contains a number of contradictory findings, and considerable conflict on every level, personal to professional. In this report, no attempt was made to present a comprehensive survey, but rather to cite on each point only the study or studies that appeared most likely to provide valid guidance.

The discussion of paper sizes has been prepared essentially from the viewpoint of the optimum size for the reader. The opinions and recommendations contained herein are my own. The overall study will deal with the economics of typist time, paper handling and storage costs, economic impact of a change in paper size on existing machines and paper processing devices, and related factors, including world standard paper sizes. It is possible that these additional considerations will result in positions different from those expressed here.

GERALD L. HOWETT

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ABSTRACT

The primary function of this report is to summarize the experimental literature on the effects of typographical variables on the legibility of printed matter. A secondary effort has been devoted to an attempt to analyze quantitatively the principles of page design, from the point of view of esthetics combined with legibility, with some intuitive consideration of other factors such as paper handling. The overall purpose is to see how these two classes of psychological factors -- legibility and esthetics -- might be taken into account in considerations of optimizing page dimensions in the standardization of paper sizes. The typographic and related variables discussed include: type style (face), type size, width (length) of the printed line, separation (leading) between lines, margins, column arrangements, paragraphing, page length, color of ink and paper, and positioning of the page relative to the line of sight. Recommendations are made for action (including further research) to bring existing practice into closer conformity with the legibility findings. A new letter-size page, 198 x 280 mm (7 3/4 x 11 in.) is proposed as another possibility for an international standard, with the understanding that practical factors not considered in this report may favor some other size.

Key Words: Esthetics, page; Golden Section; legibility; page size; print, legibility; readability; type; typography; visibility, print.

SUMMARY OF ACTION RECOMMENDATIONS

A summary of all findings and the conclusions drawn from them is given at the end of the report (section 6). Among the more important specific recommendations made for possible future action are the following:

(1) A legibility test should be made comparing speed of reading for material typed with the flush-left-margin format and with the traditional paragraph-indentation format. If the indented format is superior, the government should revert to it as its standard style.

(2) A legibility test should be made comparing speed of reading for a typewriter face that is "proportionally spaced" (that is, having several different letter widths) and a fully comparable single-letter-width face of the usual sort. If the proportional spacing is superior, as expected, the government should consider restricting its acquisition of new typewriters meant for ordinary use to those with proportionally spaced type, with due consideration being given to the increased cost of neatly correcting typing errors in which the width of the replacing symbol differs from that of the replaced symbol.

(3) As soon as financially feasible, the government (and other heavy users of computer output) should limit acquisition of computer line printers to those with upper-and-lower-case printing chains, since all-capital type markedly slows reading speed. The loss of speed for running text is sufficiently serious (10 to 20%) that replacement of current all-capital printers should be considered.

(4) Reading matter of all kinds should be positioned with the top tilted back about 45° from the vertical, to maximize speed and ease of reading. Desks with tiltable top sections or portable book racks should be much more widely employed.

(5) Since reading is slowed when the printed lines exceed a width of 5 1/2 inches, consideration should be given to typing on sheets narrower than the presently customary 8 or 8 1/2 inches, with due recognition being given to the cost of the increased number of sheets that would be needed for some longer messages.

(6) If present paper sizes are retained, consideration should be given to saving paper and optimizing legibility by typing in double-column format with narrow margins. This format might be practical for documents of which many copies will be made, but for ordinary correspondence, the cost of the increased typing time might outweigh the advantages.

(7) On the basis of a number of factors -- legibility, esthetics, and intuitive considerations of economics, handling, and potential for international agreement -- the author proposes consideration of a new letter-size page of 198 x 280 mm (7 3/4 x 11 in.). Such paper accords with the ISO standard in having an aspect ratio of $\sqrt{2}:1$, but its absolute size would be less awkward for handling and filing than the larger ISO A4 paper. This size is put forward as a candidate with the understanding that factors not analyzed in this paper could favor other choices on balance.

Legibility, Esthetics, and Page Size

Gerald L. Howett

1. INTRODUCTION

One of the factors that must be weighed in the determination of optimum page size is the legibility of the printed or typewritten material contained on the page. Ideally, from the reader's standpoint, printed matter should be presented in a typographical format that allows for maximum speed of reading, minimum visual fatigue, and maximum esthetic pleasure to the reader. Since it is possible *a priori* that these three considerations could be in conflict and thus dictate different choices of typographical arrangement, some balance among them must be selected in order to allow for a single optimum choice. Once an optimum reader-response typography has been chosen in this way, the page-size restrictions dictated by that choice must then be weighed against the various other factors that enter into page-size selection, such as economics, ease of production, ease of storage, ease of handling, and considerations of resistance to change by all those involved in formulating an agreement and carrying it out.

In the following section, it will be seen that the factor of reader fatigue does not enter as a consideration with typographies that are not extremely difficult to read. The emphasis in this report is therefore on reading speed as the primary determining factor, with reader preference as a secondary selection factor from among typographies that are equivalent with respect to the speed factor.

2. MEASURES OF LEGIBILITY

A considerable literature exists on the subject of the legibility of various typographical arrangements of written material. However, a variety of different criteria of legibility has been used. The criteria can be split into two fundamental classes: those making use of isolated letters, groups of letters, single words, or, at most, short groups of words; and, in contrast, those making use of meaningful running text involving sentences or paragraphs.

2.1. Recognition Criteria; Visibility

The first class of criteria may be reasonably referred to as recognition criteria. The tests used in these cases consist of reducing some aspect of the stimulus field to a point at which the symbols present in the field are just barely visible, and ranking the typographical configurations in accordance with the degree of degradation that can be tolerated in whatever stimulus aspect is used. Among the most common criterion stimuli that have been used in this way are: luminance and contrast (Luckiesh and Moss, 1935b), distance from the observer (Sanford, 1888), exposure time (Dockeray, 1910) and degree of blur (Weiss, 1917). [The references cited describe early uses of the respective methods; considerable later work has been done as well.] The premise that often tacitly underlies the use of these methods is that a particular typographical configuration is visible or legible, in some sense, under ordinary conditions of viewing, to the same relative degree (in comparison with other configurations) that it is legible under highly "reduced" (degraded) conditions. This premise, which is rarely stated explicitly by the authors involved, at times can be seriously in error. In essence, the premise is an assumption of lack of interaction between the stimulus variable that is manipulated and all the other variables that are kept constant. Thus, if the presence of serifs, for example, helps make letters more visible when the environment is so dark that the letters can barely be read at all, need it necessarily follow that serifs will still be advantageous when the luminance level is not a problem?

There is by no means an intention to suggest here that all the studies done with recognition criteria are worthless. Frequently, one is specifically interested in the relative merits of different typographical arrangements under reduced conditions. For example, highway signs should be visible at the greatest possible distance; street signs not lit up at night should be visible with a minimum level of illumination; and dials in an airplane should be readable in the shortest possible time. When the information sought, however, relates to the legibility of running text under relatively normal reading conditions, results obtained with limited-length texts under reduced conditions must be treated with considerable skepticism. Some empirical evidence to support this point is cited later.

2.2. Prolonged-Performance Criteria; Legibility

It is easy to understand the temptation to use reduced conditions even when the primary interest is in relative performance under normal conditions. The problem centers on the phrase "relative performance"; performance as measured how? If viewing conditions are so good that any reasonable typographic arrangement is clearly legible, on what basis can the experimenter rate one arrangement "better" than another? Criteria of the second class, which might be called prolonged-performance criteria, represent a direct attack on this not at all simple predicament. The studies using these criteria usually measure reading rate, sometimes check reading accuracy (comprehension), and sometimes try to assess visual fatigue during or following a period of reading.

a. Vocabulary

The quality being measured by prolonged-performance criteria is usually called "legibility", whereas the quality measured by recognition criteria is most often referred to as "visibility". Finally, the term "readability", sometimes used as a synonym for "legibility", is now used mostly to refer to the ease with which the meaning of a passage can be apprehended. Readability deals with such factors as sentence length, number of syllables per word, grammatical construction, etc. -- cognitive rather than visual variables. Some authors are trying to encourage a strict preservation of the distinction between these three terms, and such distinction would surely be helpful.

A recent explicit call for maintenance of the separate meanings was made by Foster (1968), who provided succinct definitions, as follows:

Readability: "comprehensibility due to the style of writing."
Visibility : "identifiability of a printed character or form."
Legibility : "the ease with which running text matter can be understood under normal reading conditions."

b. Fatigue

The use of fatigue as an indicator of relative undesirability in a typographical arrangement has an intuitive appeal, since one might expect that even under good reading conditions, a sufficiently sensitive measure of visual fatigue would allow discrimination among different typographical arrangements. Unfortunately, the experimental facts do not clearly support this intuitive viewpoint. Luckiesh and Moss (1937, 1939a) believed that the rate at which a reader blinks his eyes is a sensitive measure of the difficulty level of the reading task. The blink rate has several advantages: it is an objective measure, and variations in the rate are expected to manifest themselves almost immediately. Luckiesh and Moss did a number of reading studies using this measure and others have used the measure since. However, Bitterman (1945) and Bitterman and Soloway (1946 a, b), after careful attempts to replicate the Luckiesh-Moss results, rejected the blink rate as not reliably correlated with visual task difficulty. Tinker (1946, 1948) sides strongly with Bitterman in this matter, and in fact asserts: "Every other investigator (except Luckiesh) who has attempted to validate the blink technique as a measure of ease of seeing or legibility of print has obtained only negative results" (Tinker, 1963, p. 19). Heart rate, which Luckiesh and Moss (1935a) had also found to be an index of visual effort, was also rejected by Bitterman (1945), and, unlike blink rate, has seen little later use.

If blink rate as a measure of momentary visual effort is, at best, controversial, one might still hope that some measure of cumulative fatigue after prolonged periods of reading could be found. A very careful and elaborate study by Carmichael and Dearborn on this question, to the description of which they devoted an entire book (1947), regrettably led to a negative conclusion. They monitored blink frequency and the pattern of eye movements during six-hour periods of reading under favorable conditions and found no significant changes in either measure during the entire reading period. They expressed the opinion that deterioration might be detectable after extremely prolonged sessions of reading, but that such deterioration would be more a matter of sleep deprivation than cumulative visual fatigue due to the reading. In essence, then, even though fatigue is one of the most important factors in many practical performance situations of other kinds, it can be ruled out as a consideration here because people are too good at reading to show any fatigue differences among reasonably normal typographic arrangements. There seems to be little doubt that reading under particularly unfavorable conditions -- low luminance, poor contrast, very small type, glare sources present, etc. -- can lead to obvious fatigue effects such as burning eyes, headaches, or dizziness. Scientific literature on such extreme effects is meager, and the primary concern here is with more normal ranges of visual stimulus conditions.

c. Reading Speed

We are left, then, with reading speed as the last obvious candidate for a measure applicable as a prolonged-performance criterion. It would certainly be an embarrassment if speed, too, were found not to vary consistently with changes in typography. In fact, Luckiesh and Moss (1938, 1939b, 1940a, 1940b, 1941) repeatedly found that their tests of speed of reading were much less sensitive measures of ease of seeing than the eyeblink rate. The design of adequate experiments in reading, and in speed of reading in particular, is very far from being simple or straightforward. Careful controls of various sorts are a necessity, and many choices among possible procedures must be made. Evidently, Luckiesh and Moss, who used several different speed-of-reading tests, were not lucky enough to hit upon the right combination of procedural elements to yield good sensitivity. Paterson and Tinker, however, and later Tinker alone and with other coworkers, do seem to have developed a highly sensitive procedure for testing reading speed that correlates quite well with fairly small changes in typography. The reading material used, which keeps the comprehension level fixed at essentially 100%, is from the Chapman-Cook Speed of Reading Test (Educational Test Bureau, Minneapolis, Minn.), and, for longer tests, the Tinker Speed of Reading Test (University of Minnesota Press, Minneapolis, Minn.).

Tinker's high productivity and experimental sophistication have resulted in a situation quite rare in the modern world: domination of a field of research by a single individual. Two of the most useful review books on the subject of legibility are one by Paterson and Tinker (1940) and a later, updated version by Tinker alone (1963). Tinker also has a book (1965) that covers the field of reading more broadly, including a summary of the legibility work, and also extended discussions of eye movements, lighting, comprehension, and other aspects of reading. Many of the journal articles cited by Tinker in his books are his own work. The 1963 volume, Legibility of Print, contains a bibliography of 238 references. Of these, Tinker is an author -- sole, senior, or junior -- of 95, or 40%. While it is difficult not to receive a clear impression from Tinker's books that he believes strongly in his own approach and considers a number of the experiments of other authors to suffer from procedural or logical defects, his listing his own work as 40% of his 1963 bibliography is not a reflection of megalomania; he has in fact contributed more to knowledge in this specialized field than anyone else, although 40% might possibly represent a somewhat higher valuation than some other authors in the field might want to give. Tinker is a psychologist, well trained in the design of experiments, and fully aware of the importance of careful controls. A number of the other workers who have published on legibility have come to the field from backgrounds as artists, typographers, and other non-scientists, and some of them -- I agree with Tinker -- have left their experimental procedures open to criticism. I do not mean to suggest here that Tinker's own work is beyond criticism, but it does form the most convincing large body of evidence yet available on this subject.

Another recent book on legibility that emphasizes esthetic considerations more than Tinker's works do is by Zachrisson (1965). This book seems to be popular with typographers, who are not satisfied with Tinker's rigidly operational approach (Baudin, 1967). Since the emphasis in the present review is on "hard" experimental evidence, most of the findings to be referred to will be Tinker's.

A recent brief work (107 pages) by Spencer (1969) contains a thorough, well-illustrated summary of legibility research, and a fine 464-item bibliography (including 123 Tinker references, or 26.5%). It is a fair, balanced treatment that tries to integrate the contributions of both the typographic designers and the experimentalists.

3. VARIABLES THAT HAVE BEEN STUDIED

The only practical method of achieving the high visual quality (sharpness and blackness) of ink printed onto paper is to print ink onto paper. As a result, almost all studies of typographical factors in the legibility of printed material have been carried out using established type faces and sizes and actually printing the text materials to be compared. To investigate a non-standard typographical arrangement would involve the prohibitive expense of having a new type font custom-created for the experiment. Thus, even scientifically oriented workers have not only used standard typographies, but have rather naturally used the traditional printers' units and terminology in describing their experiments. While the use in the past of available type faces and sizes cannot be reasonably criticized, the continued use of traditional printers' terms to describe what has been printed is not consistent with general scientific practice. The difficulty is not only a matter of units; some of the printing terms are simply not precise, as we shall see shortly. Even non-scientists are strongly aware of the problem (Tanselle, 1967). For the purposes of the present report, however, the variables must be discussed in traditional terms, and a few definitions will be necessary.

3.1. Dimensions and Units

For hundreds of years, printed works were produced from metal type composed into the desired message by a printer operating by hand. Later, composition of the metal type was aided by the use of machines. In recent times, however, much printing no longer involves metal type at all. Optical, photographic, electronic, and computer technology all play major roles in modern communication of the written word. This report will not concern itself with printing methods at all; the interested reader is referred to an up-to-date text such as Strauss (1967).

Many readers, however, will be unfamiliar with even the basic vocabulary of printing, which will necessarily be used in the discussions of the dimensions and units of printed matter. This basic vocabulary arose during the early days of hand-composed metal type, and the explanations that follow are phrased in terms of that now largely outmoded technology.

a. Type Size

A type is a rectangular metallic block with a raised letter or symbol embossed on one face. The printed image (often also called "type", colloquially) was produced, in the older technology, by coating the raised letter with ink and then pressing the metal type (usually as part of a block of many types) against a sheet of paper. The height (length) of a printed letter thus corresponds to the length of the embossed letter on the type. Unfortunately, the traditional specification of type size is not a measure of the actual height of the letter, but rather of the rectangular face of the type on which the letter is embossed. The letter does not occupy the full height of the rectangular face, and in different fonts (that is, sets of type of particular style and size), the same letter occupies different fractions of the full height. Thus a statement of the type size determines only approximately the height of the printed letters.

The customary unit of type size is the <u>point</u>, which originally arose in France and was defined in units outside of the English or metric systems. The American point, which differs somewhat from the French point, is closely equal to 1/72 inch, an approximation good enough for most practical purposes, including those of the present report. [The exact definition of the American point (Updike, 1962; Strauss, 1967) is, in effect, 35/996 cm., or about 0.01383 in.; whereas 1/72 in. is about 0.01389 in.] Thus 12-point type is printed from metal blocks 1/6 of an inch high, but the printed letter images are somewhat smaller. A 10-point face that occupies an unusually large fraction of the full height of the metal type may appear to be of essentially the same printed height as an 11-point face that occupies an unusually small fraction of the full type height. In fact, Zachrisson (1965, p. 201) says that "there are types which have a larger design in 10-point than others in 12-point".

b. Separation of Lines

One line of print is produced from one row of metal types. Frequently, the next line is set by jamming the next row of types directly against the first row. Material printed in this way, with no space between successive rows of type, is said to be set solid. The printed lines, of course, show a definite separation because of the fact mentioned above that the raised metal image of the letter occupies less than the full height of the type block. In fact, it is the interval from one line to the next (measured between corresponding parts of a particular letter appearing on both lines), not the size of the letters, that is directly equal to the type size when type is set solid.

When it is desired to introduce extra separation between lines, a thin strip of lead is inserted between the rows of type. The height of this strip is specified in points, and is referred to as leading. Most type fonts today are produced in sizes of integral numbers of points, although some smaller fonts are made in half-point sizes, and some of the very old fonts have to be measured to the nearest 0.1 point. The amount of leading used in printing is usually from 0 to 2 points, in half-point steps, although more may be used, particularly with very large type sizes. In the examination of rare old books, printed with an unfamiliar type font, it is sometimes not clear whether the type used was, say, 9-point set solid or 8 1/2-point with 1/2 point of leading. There is simply no way to tell for sure from carefully printed text how much of the space between lines is due to the "margins" (in typographical jargon, the "shoulders") above and below the letters on the type blocks, and how much to extra leading. Since the fraction of the type height taken up by the upper and lower "margins" varies only over a relatively narrow range, an experienced typographer can usually separate the type size from the leading by comparing the height of the printed letters to the interval between lines, but with unknown old type fonts an uncertainty of 1/2 point is common, and, in extreme cases, the margin of error may be a point or more.

The student of reading, as opposed to the typographer, is concerned only with what appears on the printed page and not with how it got there. A measure of the height of the printed letters, plus a measure of the empty space between adjacent lines, would be the best method of specification from this point of view. Since the letters of a lower-case alphabet have at least several and sometimes many different heights, both above and below the main line, it will not be a trivial achievement to define unambiguous units of this kind. In the meantime, line separations are specified in points of leading.

c. Line Width

In colloquial speech, it is more common to refer to the length of a line of print, rather than the width. Some typographers, however, customarily use the term "width" to refer to any lateral (left-right) dimension on the page and "length" or "height" to refer to vertical (top-bottom) dimensions. That convention will be adopted in this report.

In standard typewriter fonts, the types for all letters have the same width. The printed letters may vary somewhat in width, but the same amount of lateral space, including the accompanying blank space on both sides (corresponding to the side "margins" on the type body), is devoted to each letter. In all fonts normally used for commercial printing, however, there are a number of different widths represented by the letters of the alphabet. A unit called the em was created as a kind of standardized letter width for type of a given size (height). The em is a width equal to the type size. Thus one em for 10-point type is a width of 10 points (10/72 inch), one em for 12-point type is a width of 12 points (12/72 inch), etc. Finally, in order to have a single absolute unit of width, independent of type size, the 12-point em was chosen as the master standard of width. Since the old name for 12-point type was "pica", this unit, equal to 12/72 = 1/6 inch, is called the pica. Thus the number of picas in a line is simply 6 times the number of inches. (When greater accuracy is necessary, a more exact factor is 6.0234. See section 3.1.a.)

It should be noted that the typewriter face known as pica is in fact a 12-point type (6 lines per inch of paper height), with each letter occupying a fixed width of 1/10 inch; whereas elite type is also 12-point, but each letter has a width of 1/12 inch (= 6 points = 1/2 pica). Elite letters are shorter as well as narrower than pica, and have the approximate appearance of an average 11-point book type.

3.2. List of Variables

The following list includes the principal typographical variables that will be reported on in this review.

(1) Type style (face).
(2) Type size (expressed in points).
(3) Line width (expressed in picas).
(4) Leading (extra space between lines, expressed in points).
(5) Margins.
(6) Column arrangement.
(7) Paragraphing.
(8) Color (of print and paper).
(9) Positioning of the page.

Many of these variables have effects that are not independent of each other. Tinker is aware of the problem of interaction and has devoted considerable care to investigating the interactions of three variables: type size, line width, and leading. The optimum value, in terms of speed of reading, of any one of these three factors depends on the values of the other two factors.

Paterson and Tinker (1940) have also shown that combining two or more non-optimal typographic arrangements leads to a total retardation of reading speed greater than that due to each separate factor, but rarely as much as the simple sum of the separate losses. The combination of arrangements, each one of which is only marginally non-optimum (that is, causing by itself a loss that is not statistically significant in a group of readers of the size used for the tests), can produce a loss of speed that is definitely significant.

a. The Principle of Familiarity

It will be seen in reading through the various results to be presented in the following section, that a number of these experimental findings can be explained by the hypothetical but rather obvious principle that we are slowed down in reading by any unfamiliar feature of the material. Conversely, within the limitations imposed by visual physiology, we read most quickly with a typographical arrangement that is most familiar.

Paterson and Tinker (1940) not only measured reading speed objectively, but also often asked their subjects to rank the typographical arrangements being compared in terms of preference, pleasingness, and estimate of legibility. In many cases where there were no significant differences in reading speed, there were strong differences in these subjective ratings, and here, too, familiarity was a clear contributing factor.

Since the source of our familiarity is actual printing practice, and since fashions in typography change over the years, it follows that the results of tests conducted today might differ in some details -- particularly in terms of preferences -- from the results obtained by Paterson and Tinker 30 or 40 years ago.

4. THE EXPERIMENTAL RESULTS

4.1. Type Style (Face)

Typographers devote much more attention to type style than to any other factor. They are guided by esthetics and intuitive considerations of "appropriateness" or "congeniality" (Zachrisson, 1965) of the type style to the message content. Paterson and Tinker (1932) collected data on the effect of type style on reading speed and also obtained preference ratings from their subjects. They found that all of the most commonly used faces are equally legible, although there were considerable variations in the readers' preferences. Only really unusual type styles are read significantly more slowly than the popular faces. The worst they tested was Cloister Black (Old English). One might reasonably expect the lower familiarity of the forms of these letters to have a slowing effect.

Unfortunately, another deviant type style that significantly retards reading speed is American Typewriter, the standard type face used on many typewriters. This retardation should be of interest to government and industry -- it costs money. It should be noted that Paterson and Tinker did not produce the American Typewriter samples on a typewriter, but had the material printed from type, as with all the other fonts. Thus the inferiority of American Typewriter in their tests cannot be ascribed to the lower contrast that characterizes most typed (as compared to printed) material. The forms of the individual letters in American Typewriter type are not very different from the forms used in ordinary printing, so the most obvious source of the difficulty is the constant-letter-width feature of ordinary typewriter type. Recently, Payne (1967) apparently confirmed that this is indeed at least part of the problem. He compared material typed in IBM modern, a face with so-called proportional spacing (four different letter widths), to the traditional one-width IBM elite. Speed-of-reading tests showed significant speed increase with the proportional spacing, with no loss of comprehension. An interesting interaction effect was found: the more difficult the reading material (in terms of meaning), the greater was the superiority of the proportional spacing. Unfortunately, Payne's study suffers from a defect quite common in legibility research--the confounding of variables. The source of the difficulty is the practical necessity of working with existing type fonts. IBM Prestige Elite is a 12-point face but the proportionally spaced IBM Modern is 14-point. The superiority of Modern could be due simply to the larger type size, rather than the proportional spacing. Strangely, Payne claims that the greater point size of Modern refers only to the line spacing (still another confounded variable), and the heights of the characters are the same in both faces. He says that the differences lie only in letter-width, letter-spacing, and word-spacing, all variables in the lateral dimension. However, samples of the two styles of typing are printed as Figs. 1 and 2 in his paper, and the vertical height of the Modern characters, as reproduced in the figures, measures clearly greater than the height of the Elite characters. There seems no reason to doubt Payne's basic conclusion about the superiority of proportional spacing, but further research seems warranted to develop unequivocal evidence.

Paterson and Tinker (1932) found that readers prefer heavier faces, that appear to border on boldface, but these styles are not actually superior in legibility. On the other hand, a modern serifless type they tested (Kabel Light) was disliked by readers, but was just as legible as the more ordinary serifed types. The same was true of full boldface type. Both of the latter findings can be explained by the principle of familiarity. However, sans-serif type has been used more and more since the 1930s, and today may be somewhat less disliked by the reading public. Possibly, some esthetic factor other than simple unfamiliarity may contribute to the negative reaction to sans-serif styles. A recent preference study among German readers (Becker et al., 1970), not including any test of reading performance, concluded that there were "rather strong preferences" for the traditional, serifed faces tested, relative to a sans-serif and to an italic face.

The problem with italic print goes beyond esthetics into actual performance. Paterson and Tinker (1932) found that italic print is read more slowly than ordinary roman, particularly with low illumination or small type size. The printing of long blocks of text in italics is best avoided.

All-capital print is read much more slowly (10 to 20%) than lower case. Normal adult readers recognize whole words in lower case by the characteristic forms of the words, determined largely by the location of ascenders (strokes rising above the main line -- defined as the vertical space occupied by a lower-case x -- as in b, d, f, l, etc.) and descenders (as in g, p, q, y, etc.). These strong patterns are missing in upper case, and readers must rely on less conspicuous and less familiar spatial forms. Capitals also are at least 1/3 wider than corresponding lower-case letters, so that more lines are required to print a given amount of text. This not only wastes paper (hence money), but requires more fixation pauses of the reader, another factor that slows him down. Paterson and Tinker advise avoiding all capitals completely, and their research results obviously are of considerable interest to heavy users of computer output.

The inferiority of all capital letters as judged by reading speed is a prime example of the irrelevance, for the situation of continuous reading, of isolated-character recognition measures (visibility) based on perception at a distance or with lowered luminance; in such tests, capital letters are seen more easily (Tinker, 1932). Different type faces also vary in their visibility, as measured by recognition tests, but these results have no correlation with the results of reading-speed tests. Tinker misses few opportunities to stress these disagreements.

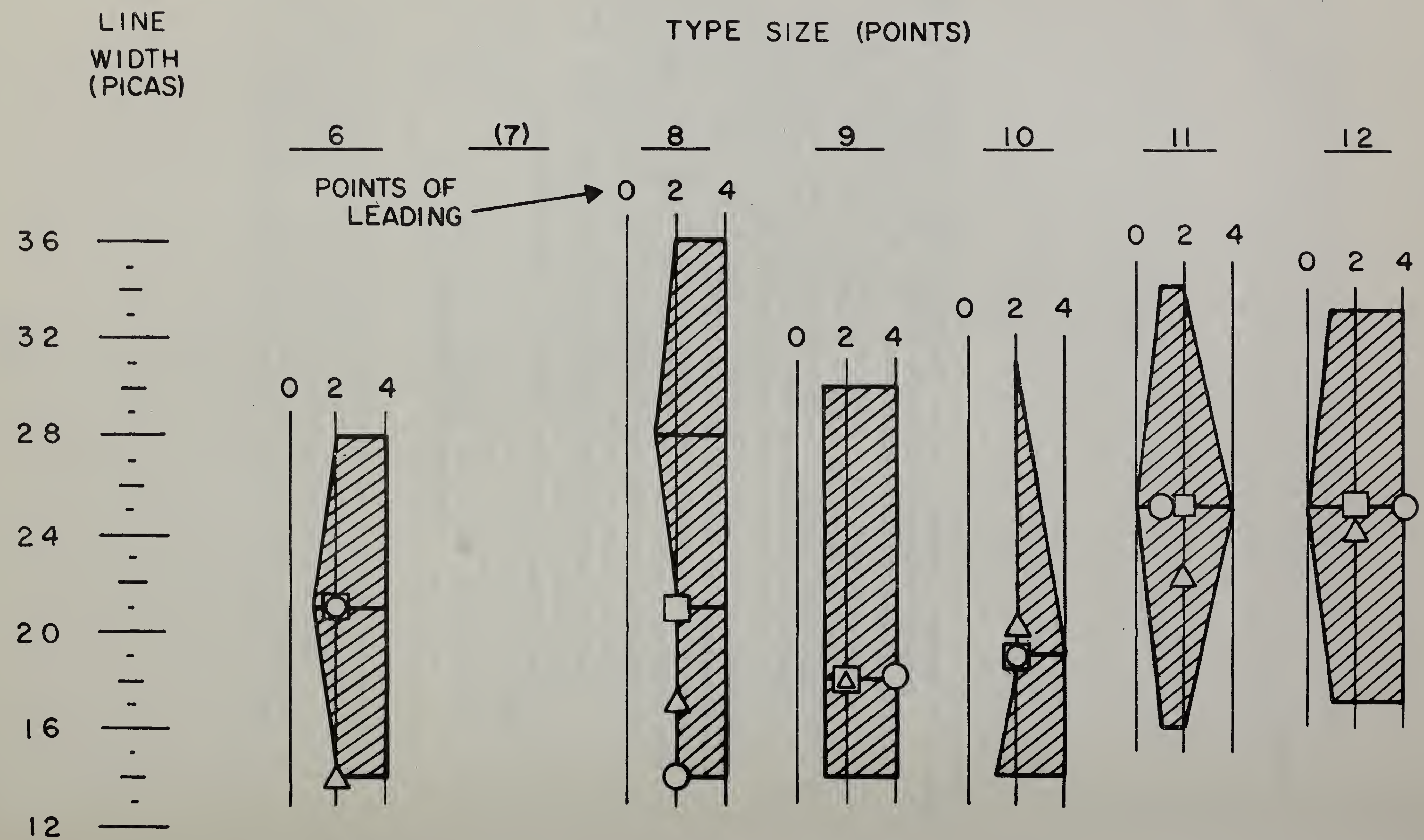
4.2. Type Size, Line Width, and Leading

Paterson and Tinker (1940) carried out a very extensive series of studies of the effects on legibility of various combinations of line widths and leading, for each of six type sizes. For each type size, there is a range of line widths and leadings for which there is no significant loss of legibility. These "safety zones", as Tinker calls them, are illustrated in Fig. 1.

The figure reveals that although there may be a slight tendency for the optimum range of line widths to move to higher values with increasing type size, the location of the range is more or less independent of type size, as is the extent of the range. A range of 17 to 28 picas lies within the safety zone for all six sizes of type.

Figure 1. "Zones of safety" for six sizes of type, according to the data of Paterson and Tinker (1940). Four levels of leading were used in these experiments: 0, 1, 2, and 4 points. All configurations for a given type size were compared in terms of reading speed to a fixed standard, shown by a square. The shaded region for each type size indicates the ranges of line width and leading that are considered essentially optimum. The circle within each region indicates the particular configuration that yielded the very highest reading speed relative to the standard, although in most cases this result should be regarded as a meaningless statistical accident. The triangles show the configurations chosen by Paterson and Tinker as optimum on the basis of the "safety zone", plus considerations of reader preference and printing practice. The horizontal segments within each zone, including the top and bottom levels, indicate the line widths (within the safety zone) actually tested for each type size.

[FIGURE ON NEXT PAGE.]



LINE
WIDTH
(PICAS)
TYPE SIZE (POINTS)
6
(7)
8
9
10
11
12
POINTS OF
LEADING
0 2 4
36
32
28
24
20
16
12

It is also clear that leading is helpful to legibility, although the effect is less pronounced for the larger sizes (11 and 12 points). Two points of leading seems roughly the best; for every type size, two points of leading is within the safety zone over the full range of acceptable line widths. On the other hand, too much leading can retard reading; four points is definitely inferior to two points for 10- and 11-point type.

Figure 1 does not allow for any speed comparison between different type sizes. Paterson and Tinker (1940) chose for each size of type one particular combination of line width and leading that was their guess as to the very best possible configuration within the safety zone; these optimum choices are shown as triangles in Fig. 1. One of these six configurations -- 11-point type, leaded 2 points, in a 22-pica line -- was chosen as the standard against which to compare all the others. The results showed that with these optimum line widths and leading, all sizes of type from 9 to 12 points do not differ significantly in legibility. Eight-point type significantly retards reading, and 6-point type causes a still more serious slowing down.

Paterson and Tinker (1940), in connection with an experiment comparing speed of reading for type sizes from 8 to 12 points in a fixed, non-optimum configuration of a 19-pica line set solid, obtained reader judgments of legibility (ease and speed of reading) of the various sizes of type. The readers ranked 11-point first, and that size of type has also become increasingly popular in printing practice. In the performance part of the study, 11-point type also showed the best speed of reading by a significant margin. All in all, Tinker seems to have concluded that 11-point type is the best size for general printing use. It is perhaps significant that elite typewriter faces, which have tended to replace pica over the years, have a letter height more or less corresponding to 11-point. Since the interval between single-spaced lines of standard elite (as well as pica) is 12 points, material typed in elite might be thought of as roughly equivalent to 11-point type with 1 point of leading. This is essentially the Tinker-Paterson ideal.

As indicated in Fig. 1, the very best line width for both 11- and 12-point type is just over 4 inches (25 picas). There is a loss of speed indicated by the data for all greater line widths, but the loss is not statistically significant until the line width exceeds the 5-1/2-inch (33-pica) top of the safety zones. The Paterson-Tinker (1940) data show that for 11-point type with one point of leading, similar to elite typewriter type, material set in a line width of 7 inches (43 picas) is read about 5.4% more slowly than in the optimum 4-inch width. Material printed in 12-point type set solid, similar to pica typewriter type, shows a corresponding retardation of about 7.3%. The data suggest that the speed loss increases very rapidly beyond a 7-inch line width.

4.3. Page Layout

a. Margins

The use of margins is traditional and is often justified on the basis of esthetics, alleged resting of the eyes before and after each line and each page, alleged focussing of the reader's attention on the text by the "framing" effect, providing space for the writing of notes, and allowing for wearing of the page edges without encroachment on the text area. Paterson and Tinker (1940) found in a survey among some of their experimental subjects that most readers (62 per cent) believe substantial margins to be justified in terms of improved legibility, and another 27 per cent think they are justified for esthetic reasons.

Since the opinions of readers frequently do not correspond with actual reading-speed performance, Paterson and Tinker (1940) investigated directly the effect of margins on legibility. Surprisingly, they found that material printed on a page with no margins at all (actually, 1/16 inch) is read as rapidly as material printed on a page with traditional ample margins. I was unable to find in their book a specification of the color or reflectance of the background surrounding the test pages visually during reading. The background might be a significant visual factor in the case of the "no-margin" pages.

Quite commonly, the inner ("gutter") margins of a book are the narrowest of all. In thick books, the pages often have considerable curvature in this region. The Paterson-Tinker study showing the uselessness of margins from the legibility standpoint used flat sheets of paper. In a later experiment, Tinker (1957) investigated the effect on reading speed of curving the page being read around a cylinder. A definite reduction in reading speed was found for the curved pages. Thus Tinker believes that although upper, lower, and outer margins do not add to legibility, inner margins should be made considerably wider than is customary in order to reduce the typical inner-edge curvature and improve legibility. Adoption of this recommendation by printers would have the additional practical advantage of allowing for easier and more legible photocopying out of thick books and bound journals.

In addition to the problem of the size of margins, there is also the issue of how even they should be. Paterson and Tinker (1940) checked out an earlier suggestion by Cattell, published by Dearborn (1906, p. 39), that indenting every other line at the left by a few millimeters would make it easier for the reader's eye to locate the beginning of the next line, and thus increase reading speed. The actual test showed that this arrangement significantly retarded speed of reading. The obvious explanation for this result is the principle of familiarity (section 3.2.a).

The use of flush left margins is virtually universal. It has also been considered highly desirable by printers for the right margin to be flush ("justified"), and so enough additional spaces between words are inserted in each line of type to bring all printed lines to the same total width. Two studies concerned with newspaper typography (Wiggins, 1967; Davenport and Smith, 1965) concluded that speed of reading is the same with and without justification of the right margin. In fact, Wiggins' results suggest that if there is any difference, reading speed with justification is slower, presumably because of the resultant variations in inter-word spacing. An experiment by Fabrizio, Kaplan, and Teal (1967), using the Davis Reading Test (speed and comprehension) plus eye-movement recording, concluded that there are no legibility difference between three right-margin configurations: justified, irregular, and irregular with a printed guideline (rule).

We are accustomed to reading unjustified typed and handwritten material, so both justified and unjustified formats are familiar. Usually, the degree of line-width irregularity in unjustified material is somewhat reduced by the device of hyphenation. In the Davenport and Smith study, one of the formats used consisted of unjustified material that was also completely unhyphenated and, since the copy was in narrow newspaper columns, the visual impression of irregularity in the right margin was maximal. Still, there was no penalty paid in the speed of reading such material, so the evidence seems to indicate that justification is a typographical device that serves an esthetic, and not a functional purpose. Actually, recent evidence (Becker et al., 1970) suggests that, at least among German readers, there is not even an esthetic preference for justified printing.

b. Columns

Multi-column page formats have become increasingly popular in textbooks and scientific journals since the 1930s, and remain popular in non-technical magazines. Both readers and typographers strongly prefer double-column printing over the single-column arrangement. Paterson and Tinker (1940) studied the effect of various kinds of column separations on the legibility of double-column material. The separations studied included several widths of blank separating space: 1/2, 1, and 2 picas; and a rule (printed vertical line) with various amounts of space on both sides: 0, 1/4, and 1/2 pica . All these arrangements were equally legible, a finding that suggests that any unequivocal signal that the end of the column has been reached is as good as any other.

There were, however, definite preferences among the readers. The best-liked separation is a rule with a 1/2-pica space on each side, and simple separations of 1 and 2 picas are also well liked; the other formats are disliked. The most common separation used in printing is (or was in 1940) a 1-pica space, so that in this case practice coincides rather well with reader preference, at no cost in legibility.

c. Paragraphing

Paterson and Tinker (1940) found that splitting text into short paragraphs with the first line of each paragraph indented improves speed of reading by more than 7 per cent over a format with fewer, longer paragraphs. In view of this experimental evidence, the practice instituted several years ago of maintaining flush left margins in all typed U.S. federal government correspondence probably should be re-examined. Omission of the indentations at the beginnings of paragraphs may result in a pleasing "modern" look, and may save a very small amount of paper every year, but if it really takes a reader an average of 7 per cent more time to read a non-indented letter than an indented one, the cost to the government and to the public of maintaining the new format may be substantial. It may be, however, that the skipped lines between paragraphs incorporated in the government format are at least as effective a visual cue as indentation. A direct speed-of-reading test seems desirable.

d. Page Length and Proportions

The length of a page does not appear to be a factor that would have an important direct visual effect on reading speed, everything else being equal. However, it is obvious that there must exist an optimum page length, somewhat dependent on the page width and paper stiffness, in terms of overall performance in reading a given printed text. Assume that all typographical factors are kept fixed other than the length of the page, and consider a particular long message, such as a book. On one extreme, we could print the book on pages shorter than they are wide -- in fact, one line to a page, in the ultimate case. The problem here is repeated interruption and also excessive handling time. The physical act of turning pages takes time, the visual act of finding the first word on a new page takes time, and the psychological frustration of the repeated interruptions of the absorption of information would irritate the reader, and perhaps cause his attention to wander more than usual. It may also be that good readers are accustomed to glancing ahead on a page they are reading so as to have some idea of the general nature of the material coming up soon. If this anticipatory peeking is in fact common, the use of very short pages would have that additional retarding effect. Finally, if the pages are bound, the sheer thickness of the book would be preposterous; if the pages are not bound, dropping them would be a disaster.

The other extreme would be printing the book on enormously long pages -- in the ultimate case, on a single sheet many feet in length (a vertical scroll). The main problem here would be one of handling. It is faster to turn a page than to roll-unroll a scroll. If the scroll were long and one end accidentally rolled off the table, the re-rolling process would be time-consuming and frustrating. Even if the pages are only, say, three feet long, so that there is no real scroll effect, a handling problem still exists. With unbound long pages, a certain amount of pushing up can be done as the reader progresses down the page, but the reader has to begin with most of the page hanging annoyingly off the table into his lap. With bound long pages, and to a lesser extent with unbound pages, the reader will tend to keep the pages in a fixed position on the desk and move his body, head, and eyes. If the top of the page is quite far from the reader, the print there will subtend a smaller angle and so be less legible, and it will also be tilted at a more shallow angle from his line of regard, a factor that will be mentioned in the following section as retarding reading speed.

Thus, since both extremes of page length are bad, the best length is to be sought somewhere in between. Perhaps a rough specification of the optimum length is the greatest length that permits the page to be dealt with comfortably, from the manual and visual standpoints, with no vertical shifting. In other words, if you can hold the page, or put it down, in a fixed position, and still read the whole page without discomfort, it is in the right range of length.

In actual practice, five primary considerations have entered into determining the page lengths actually used: (1) the width of the printed line; (2) the proportions of the margins to each other; (3) the fraction of the page area devoted to margins; (4) the aspect ratio of the page; and (5) traditional page sizes. Legibility does or at least should play some role in the choice of line width, but the other four considerations involve a mixture of varying proportions of esthetics and economics.

A number of authors have given various rules for the ideal relative proportions of the four margins on a page. Once the width of the printed line is settled upon, these margin proportions determine the absolute length and width of the page when an additional specification is made of what fraction of the page area should be devoted to the margins. In ordinary printing practice, as surveyed some time ago by Paterson and Tinker (1940), the margins occupy 50% of the page ($\pm$ 5%, in most cases), although a powerful optical illusion (Paterson and Tinker, 1938) leads most people to perceive the area devoted to margins as only 25%. This 50% rule, according to the same authors, is incorporated in many printer's style manuals, so to the extent the rule is followed, the absolute size of the page is largely dependent on the margin proportions, given a particular line width.

Instead of concerning themselves with esthetically pleasing relative sizes for the margins, some book designers have concentrated on the length/width proportion (aspect ratio) of the total page. Ratios of about 1.4 to 1.6 are most commonly taken as ideal. One particular ratio, much admired by the ancient Greeks and others, is known as the Golden Section (approximately 1.618). A discussion of the Golden Section and its application to page design is given in section 5 of this paper.

Finally, as with many aspects of printing, tradition plays an important role in the determination of page size. It has been traditional for the various sizes of paper for printing to be derived from a single large basic size by various numbers of foldings in half. Thus "folio" size paper is a very large art-book size formed by a single folding of the basic paper sheet, "quarto" is formed by folding folio paper in half, "octavo" by folding quarto in half, etc. Unfortunately, there has been no universal agreement on the basic sheet size, so a name like "quarto", for example, refers to a range of sizes rather than a single exact size.

The size and proportions of the pages of any particular book are determined by some subjective weighting of the five factors discussed above, and then a small perturbation is usually thrown in to express the individuality of the designer. Although Paterson and Tinker (1940) did find in a survey of actual books and journals that certain size ranges are popular for certain classes of printed matter, they concluded that "...Neither practical considerations nor esthetic ones dominate the choices. It almost looks as though the size of page is a matter of whim." They go on (1940, p. 84) to recommend the standardization of paper sizes.

4.4. Color

In terms of reading speed (Paterson and Tinker, 1931), preference (Paterson and Tinker, 1931), recognizability in peripheral vision (Taylor, 1934), and perceptibility at a distance (Taylor, 1934), black print on a white background is superior to white print on a black background. The only case (Taylor, 1934) for which white on black seems to be as visible as black on white is a sans-serif type face (Kabel Light) in large sizes (10 to 14 points); in 6-point size, white on black is significantly less visible in even this face. Thus, white on black should normally be avoided in running text, but when it is used for special effect, a large sans-serif type face should be employed.

In comparisons of material printed with various colored inks on a selection of colored papers, the essential finding is that only the lightness contrast between ink and paper is important, not the particular color combination. The minor contribution made by the chromatic component of an overall color difference, relative to the lightness component, when one or both of the fields being compared is very small, is not peculiar to reading, but holds in general. Important use has been made of this principle in the design of color television systems (Bedford, 1950; McIlwain, 1952).

The summarizing rule enunciated by Tinker (1963, p. 140) is that essentially maximum legibility is achieved provided that (a) the reflectance of the paper is 70 per cent or greater [in his 1965 book he raises this to 75 per cent], (b) the ink in which the text is printed has a reflectance no more than 1/8 that of the paper, and (c) the type size is at least 10 points. Thus the use of black or very dark colored ink on lightly tinted paper, which is usually considered more esthetically appealing and/or more "restful" to the eyes than black on white, is justified in the sense that no significant price need be paid in loss of legibility.

4.5. Positioning of the Paper

Although the position in which the paper is held during reading is not, strictly speaking, a typographical variable, the visual effects of holding the paper in a deviant orientation are equivalent to distortions of the typography. We have already made reference, in our discussion of margins, to the problem of reading from a curved page (Tinker, 1957). As would be intuitively expected, the optimum positioning of a page of print is perpendicular to the line of sight and perfectly upright (that is, with no clockwise or counterclockwise rotation within the plane of the page). Since the strain on the external eye muscles is minimal when the page is directly in front of the observer's face, the line of sight can be taken to be straight ahead -- that is, perpendicular to the frontal plane of the observer's face. Thus a more exact specification of the ideal orientation includes the requirements that the page (regarded as a plane) be parallel to the observer's frontal plane, and that the lines of print (regarded as geometric lines in 3-dimensional space) be parallel to the line connecting the observer's eyes.

a. Left-Right Tilt

If the page is held in such a way that the right edge is rotated closer to the reader -- and, correspondingly, the left edge is rotated away -- the visual effect is equivalent to printing on a trapezoidal sheet of paper with the large base to the right. Visually, each line of the text appears to be printed in type that varies continuously in size across the page, the small type being on the left. The letters vary across the page not only in height, but in width and spacing, and all the letters on the page seem thinner, in relation to their height, than normal. The spaces between lines, like the lines of print, are wedge-shaped.

The reader, of course, rarely perceives the image of the page in these terms, because of the perceptual phenomenon of shape constancy. By means of variations in accomodation (focus) of the eye lenses, and convergence of the two eyes, the reader is directly aware that the left edge of the page is further away from his frontal plane than the right edge. This awareness, combined with the higher-level mechanisms of shape constancy, permit him to perceive a tilted rectangular page, rather than an untilted trapezoidal page with distorted printing. Nevertheless, the reduced familiarity of the tilted-page configuration is sufficient to impede reading. The objective variation in the distance from the observer of the beginning and end of each line provides what is probably a further source of retardation of reading speed because the amount of change in accomodation required in reading from the beginning of a line to the end is greater than when the page is untilted.

Tinker (1954) tested the effect on both reading speed and visibility [the latter measured by the Luckiesh-Moss Visibility Meter, a luminance- and contrast-lowering device (Luckiesh and Moss, 1935b)] of tilting pages 45° and 60° away from the central position. He found clear losses in reading speed with the tilted pages, with much greater losses at 60° than at 45°. The losses in visibility were even greater, as percentages.

b. Fore-Aft Tilt

Since the ideal position for a page is perpendicular to the line of sight, and since most readers tend to prefer keeping their heads tilted forward so that their line of sight is about 45° down from the horizontal, it follows that the best position for a page for the average reader is with the top of the page tilted 45° back from the vertical. Many people read with the page lying flat on a table; that is, with the top tilted back 90° from the vertical, and many others hold their copy at an angle between 45° and 90°.

When the top is tilted back beyond the position for which the page is perpendicular to the line of sight (to some central point on the page), the effect is to make the top of the page further from the reader than the bottom. In this orientation, the visual effect is as if the page were a trapezoid with the large base at the bottom. Each line appears to be printed in a fixed size of type, but the lines at the top seem to be printed in small type that gets progressively larger for lines further toward the bottom. The space between lines also grows progressively larger as the reader's gaze moves down the page. All the letters on the page look wider, relative to their height, than normal. The margins are wedge-shaped (narrower at the top), and the line width appears to increase as the gaze moves downward. The letters at the top of the page appear not only shorter, but also narrower than those at the bottom. Although we are normally not conscious of these distortions, they are evident in a photograph of a tilted page. Spencer (1969, p. 47) has published such a photograph, which unfortunately seems to incorporate additional distortions, and also suffers from not depicting the margins (or edges) of the tilted page.

It should be realized that in the discussion so far we have been simplifying the situation considerably. In the first place, the observer's "line of gaze" is a fiction; the normal observer has two eyes and two converging lines of sight. It is useful as an approximation to define as <u>the</u> line of gaze the line which is in a sense an average of the two separate lines; that is, the line joining the point of fixation on the paper to the point on the bridge of the nose midway between the eyes. Under ordinary conditions, an observer perceives the world as if he had a single cyclopean eye located between his two actual eyes.

Even when discussion is in terms of the single, cyclopean line of sight, there are further complications. At most a single perpendicular can be dropped from the cyclopean eye to a plane rectangle, such as a page. Thus when we define the ideal position of a page as that in which the line of regard is perpendicular to the page, we must specify at what point on the page the perpendicularity is to obtain. The most obvious choice is the center point of the text area on the page (which would usually be in a slightly different spot from the center of the page itself because of the customary asymmetry of the margins).

The central reference point, through which passes the cyclopean line of sight that is perpendicular to the page, is the point of the page that is closest to the observer's cyclopean eye. Every other point on the page is further "from the observer" than the reference point. When the page is small, there is usually little awareness of this fact. On the other hand, an observer holding open a large newspaper in a fixed reading position is well aware that the top, bottom, and sides of the pages are quite far away and are difficult or impossible to read without shifting the paper. Visually, then, even for a page in "ideal" reading position, the effect is as if the letter located at the reference point were printed in the largest type size, and all other letters on the page were printed in smaller sizes. The loci of equal apparent type size are circles centered at the reference point, the visual size of the type decreasing as the gaze moves outward to the larger circles. The effect is quite similar to looking at a convex mirror (for example, a polished brass or chrome doorknob). Nevertheless, we are almost never aware of the actual visual situation. From a lifetime of experience, we automatically discount the decreasing visual size of the type away from the center and perceive uniform type over the entire page (again, the phenomenon of size constancy). All of the visual effects that we are discussing now in connection with tilting of the page must be understood to be overlaid upon the concentric-circle effect that exists on even the ideally positioned page.

When a page is tilted, the point nearest the observer (that is, the foot of the perpendicular from the cyclopean eye to the plane of the page) moves away from the original central reference point and, with sufficient tilt, off the page altogether. When the page is lying on a level table, the nearest point is the spot on the table directly under the cyclopean eye; or, if the observer's head is not over the table, the nearest point is the point directly beneath the cyclopean eye on the imaginary extension of the plane of the table top into the observer's stomach. In either case, the nearest point of the plane may be quite a few inches away from the page itself. The equal-distance contours are still circles, but the portions of the arcs that cut across the page are parts of circles of large radius, so that these contours are not very far from being straight lines.

Tinker (1956a) experimented on fore-aft tilt by using the 45° position (top tipped back from the vertical) as the standard, and comparing the standard for both speed of reading and visibility to three other positions: 90° back from the vertical (that is, horizontal); 100° back from the vertical (10° below the horizontal); and 120° back from the vertical (30° below the horizontal). Both in speed of reading and in visibility, tests with both 10-point and 8-point type showed that the 45° standard position was best, and there were very significant losses for the three more extreme tilts.

An investigation of tilts more characteristic of ordinary reading practice -- the range 45° to 90° tilt of the top of the page back from the vertical -- was made by Skordahl (1958). He compared 60°, 75°, and 90° tilts to a standard of 45°. As in Tinker's study, 45° was best and speed of reading grew progressively slower for steeper tilts. The retardations at 75° and 90° were substantial (5 and 10 per cent) and highly significant statistically (one per cent level of confidence), and the retardation at 60° was small (1.5 per cent), but significant at the 7 per cent level of confidence.

Thus deviations of only 15 or 20 degrees in the fore-aft direction from the ideal position can cause a slowdown of several per cent in reading speed. Tinker (1963, p. 257-8) recommends extensive use of 45°-tilted desk tops or book racks. Perhaps more widespread attention to this recommendation in industry, government, and education is warranted.

c. Rotation of the Lines of Print

If a page is rotated within its own plane (that is, around the line of sight as an axis) so that the lines of print are tilted away from the normal straight-across orientation, a penalty is again paid in speed of reading and visibility. In this case, the problem is not one of visual distortion, as with the tiltings that have just been discussed. Tinker (1963, p. 258) points out that the pattern of activity in the six muscles that move the eyeball around is simple for straight-across movements -- two muscles do almost all of the work; but for oblique sweeps, all six muscles are called into play. He also hypothesizes that the characteristic forms of the words, which

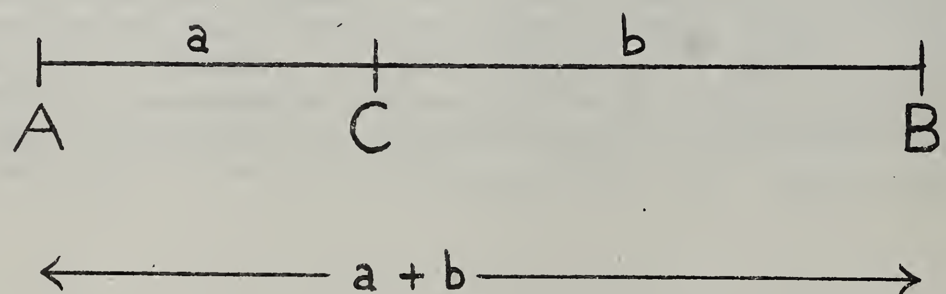
permit reading at speeds well beyond those possible with letter-by-letter recognition, are less familiar the more the line of print is rotated away from the normal horizontal orientation. Tinker (1956b) investigated the disruption experimentally, both in terms of speed of reading and visibility. The standard was horizontal print, and he tested rotations of 45° and 90°, both clockwise and counterclockwise. The plane of the page was maintained in all cases in the ideal tilt position of top 45° back from the vertical and no lateral tilt. The deficits were all highly significant. The direction of rotation was irrelevant; only the degree of rotation counted. The visibility losses were quite substantial (12 per cent for the 45° orientations and 21 per cent for the two 90° -- vertical -- rotations), but the loss in reading speed was far worse: 52 per cent for 45° and 205 per cent for vertical print. No one appears to have yet studied the effects of more moderate degrees of rotation, but there seems every reason to anticipate that even minor rotations away from the horizontal orientation should be avoided.

5. ESTHETICS AND PAGE DESIGN

5.1. The Golden Section

a. Derivation

Consider the following problem in esthetics: a line segment AB is to be divided into two parts by the point C. What position of C between A and B will divide AB in the most pleasing proportion? [See sketch.]



If C is very close to A, the contrast between the lengths a and b will be too extreme to be pleasing. On the other hand, if C is close to the midpoint of AB, so that a is nearly equal to b, the lengths will be too alike to be artistically satisfying; a moderate degree of asymmetry is the ideal. The ancient Greeks, particularly the Pythagoreans, who were interested in the mystical aspects of mathematics, decided that the ideal way of dividing the line -- any line -- is so that the ratio of the larger part to the smaller is equal to the ratio of the entire line to the larger part. Symbolically,

$$\frac{b}{a} = \frac{a + b}{b}. \tag{1}$$

We can rewrite Eq. (1) as

$$\frac{b}{a} = \frac{a}{b} + 1 = \frac{1}{\frac{b}{a}} + 1. \tag{2}$$

If we abbreviate the ratio b/a by r, the defining equation (2) can be written

$$r = \frac{1}{r} + 1. \tag{3}$$

By clearing fractions in Equ.(3), we obtain the quadratic

$$r^2 - r - 1 = 0. \tag{4}$$

There are two solutions to Eq. (4), namely

$$r = \frac{1 \pm \sqrt{5}}{2}. \tag{5}$$

The choice of the minus sign in Eq. (5) yields a negative value for r, which we can reject as meaningless, so the ideal ratio, called the Golden Section by the Greeks, is given by (replacing r by G for "Golden"):

$$G = \frac{1 + \sqrt{5}}{2}. \tag{6}$$

The approximate value of G is 1.618. From Eq. (3), we know that

$$\frac{1}{G} = G - 1 \tag{7}$$

and from Eq. (4), that

$$G^2 = G + 1; \tag{8}$$

that is, numerically, that

$$\frac{1}{1.618} \approx 0.618 \tag{9}$$

and

$$(1.618)^2 \approx 2.618. \tag{10}$$

b. Relationship to Fibonacci Sequences

The defining property given by Eq. (7) or (8) is very simple, but has a great many ramifications. For example, suppose we construct a sequence of lengths each of which is greater than the preceding length by the ideal ratio G. If we define the original length as the unit, the sequence is

$$1,\ G,\ G^2,\ G^3, \ldots,\ G^n, \ldots\ . \tag{11}$$

Now consider any member, G^n, of the sequence (11). We first note that we can write for <u>any</u> non-zero quantity the identity

$$G^n \equiv G^{n+1}/G \equiv G^{n+1} \cdot \left(\frac{1}{G}\right); \tag{12}$$

and, by virtue of Eq. (7), we can rewrite Eq. (12) for the particular quantity G as

$$G^n = G^{n+1}\,(G - 1) = G^{n+2} - G^{n+1}. \tag{13}$$

Thus, for any value of <u>n</u>, we see from Eq. (13) that

$$G^{n+2} = G^{n+1} + G^n. \tag{14}$$

What Eq. (14) says is that any term in the sequence (11) (after the second) is equal to the sum of the two terms preceding it. Such a sequence is known by mathematicians as a generalized Fibonacci sequence. In the general case, one is free to choose the first two terms arbitrarily, and then all the other terms are determined by the sum-of-the-two-preceding-terms rule.

The basic Fibonacci sequence (the one usually referred to as <u>the</u> Fibonacci sequence) is produced by choosing the first two terms both equal to unity. The first few terms of the Fibonacci sequence are

$$1,\ 1,\ 2,\ 3,\ 5,\ 8,\ 13,\ 21,\ 34,\ 55,\ 89, \ldots . \tag{15}$$

This sequence has many fascinating properties. Among them is that the value of the ratio of each term to the term preceding it, although it is different for every term, approaches a limit as you go further and further out in the sequence. The value of this limit -- not only for sequence (15) but for <u>any</u> generalized Fibonacci sequence (that is, any choice of the first two terms) -- is G, the Golden Section!

The sequence (11) is the only generalized Fibonacci sequence with the first term unity that is also a geometric progression; that is, having the ratio of each term to the preceding term constant. Simply knowing that such a sequence exists tells us that the constant ratio must be G, because, as we have just noted, the limit of the ratio has to be G.

Several elementary monographs (Vorob'ev, 1963; Hoggatt, 1969) have been written on Fibonacci sequences, with some discussion of the intriguing interrelationship between these sequences and the Golden Section.

In applications of the Golden Section to artistic design, it has been common to approximate G by a ratio of simple integers. The integers used are most commonly two consecutive members of the Fibonacci sequence (15); the more exact the approximation desired, the further out in the sequence the pair is chosen. Thus, some authors refer to the approximate proportion 3:2, some use 5:3, etc.

c. Esthetics

The proportion of the Golden Section, as applied particularly to the length/width ratio of a rectangle, has served as a guide to some designers and architects throughout post-Hellenic history. Some designers have looked upon the Golden Section as a rough general guide, and others have exhibited various degrees of stronger devotion to the principle, even to the point of mystical infatuation and a belief in the Golden Section as a fundamental law of nature. Most of the writing on this subject occurred in the period within 30 years on either side of 1900, largely in Europe, particularly Germany. A relatively recent treatise taking a broad view of the scope of the Golden Section's role in the world was produced by Hagenmaier (1949). Hagenmaier, and other earlier writers with the same viewpoint, present evidence that some of the structural proportions of many plants and animals are based on the Golden Section. With this support from nature, they recommend the use of Golden-Section proportions in man-made artifacts. Engel-Hardt (1922) wrote a work in the same spirit, but with a large part of it devoted specifically to the design of book pages in accordance with the Golden Section. His book, which is profusely illustrated with examples, deals with the design of not only ordinary pages, but also of title pages, covers, illustrated pages, etc. The treatment of the basics of the design of text-containing pages that follows in section 5.2 of this report is not based on Engel-Hardt's work, but is my own.

The allegation that people find Golden Rectangles (rectangles with a length/width ratio of G) most pleasing is, of course, open to experimental test. It was not until the late nineteenth century that one of the early experimental psychologists, Fechner, founded the field of experimental esthetics. He found (Fechner, 1876) that rectangles with an aspect ratio of G [approximated by him as 34:21; see Eq. (15)] were indeed preferred by his subjects over any of the other aspect ratios tested. However, the preference was not very sharply defined; the curve of percentage preference as a function of aspect ratio had a quite broad maximum. There was also some indication that a small secondary maximum existed for an aspect ratio of unity -- that is, a square. Later work, including some in the United States, generally confirmed Fechner's findings. The fact seems to be that a rectangle of any given aspect ratio will be preferred by some members of a sufficiently large group of observers, but the broad maximum of preference tends to center near -- not necessarily at -- the Golden Section of 1.618. The experimental work was summarized in the first edition of a book by Woodworth (1938). Sixteen years later, when Woodworth published the second edition of his book (Woodward and Schlosberg, 1954), interest in experimental esthetics had waned and the discussion of the Golden Section was dropped. An experimental paper on the Golden Section was published recently (Weintraub and Eisenberg, 1966), but it does not appear to take the subject entirely seriously.

5.2. Basic Design of Pages

a. Pages Based on the Golden Section

With no personal commitment to the status of the Golden Section as a law of nature or even a law of human psychology, it still seemed of interest to me to design a page using the Golden Section in as many ways as possible, just to see what it looked like. The result is shown in Fig. 2. All four pages in the figure, in which the lined areas represent the portions of the pages on which the text is printed, have the same proportions in every respect; only the orientation varies. The lower design has the traditional thin inner margins, the outer margins being wider by the ratio G. The upper design is reversed, the inner margins being G times the width of the outer margins. This design takes account of the improved legibility that results, as we have pointed out earlier, from making the inner margins wide enough to reduce the page curvature in the vicinity of the "gutter". A page with equal inner and outer margins was also designed, and is shown in Fig. 3. The equality of these margins eliminates one use of the Golden Section in the design, and so from the standpoint of a mystical Golden-Section devotee, the design ought to be somewhat less appealing than the designs of Fig. 2.

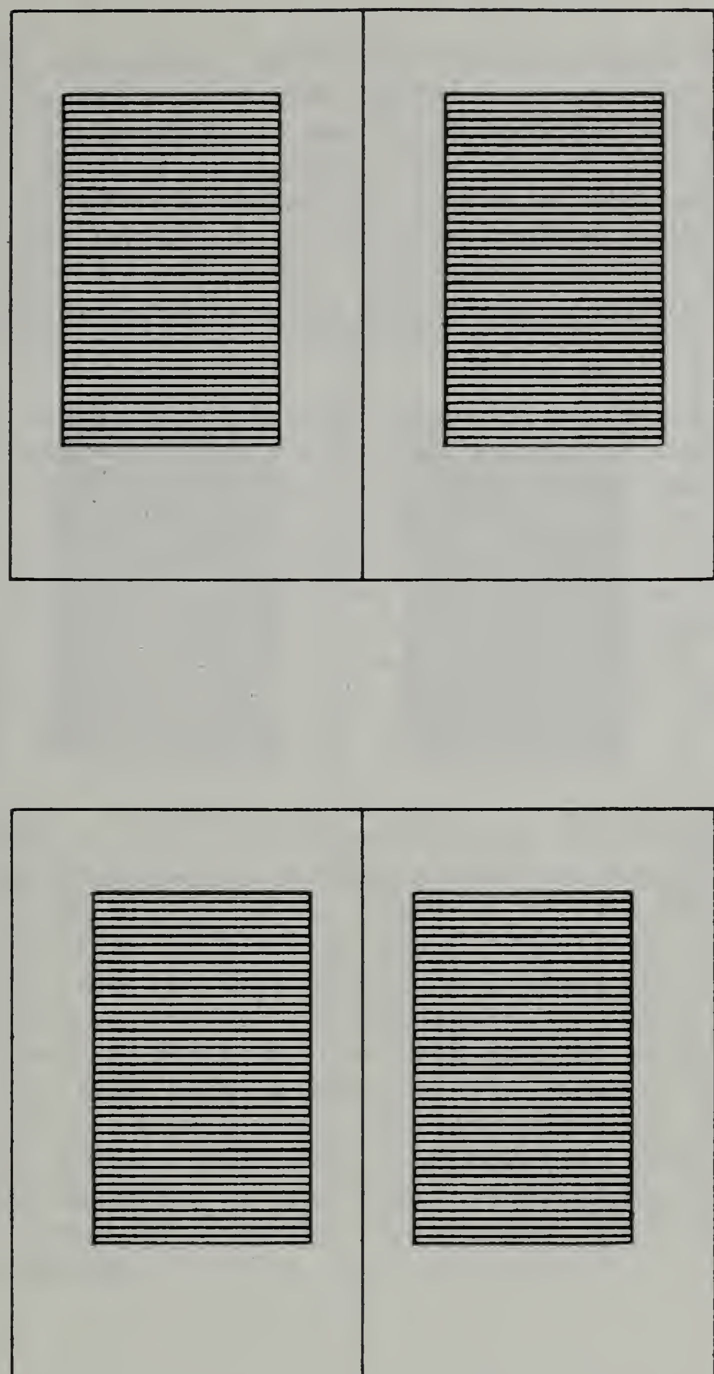


Fig. 2. Appearance of books having ideal "G" pages. The lined area represents the region in which the text is printed. A number of the proportions of various dimensions of the page and text area are equal to G, the "Golden Section" [see text]. Lower display: traditional narrow inner margins. Upper display: all proportions equal to those of lower display, but the wider side margins are placed in the inner position to improve legibility.

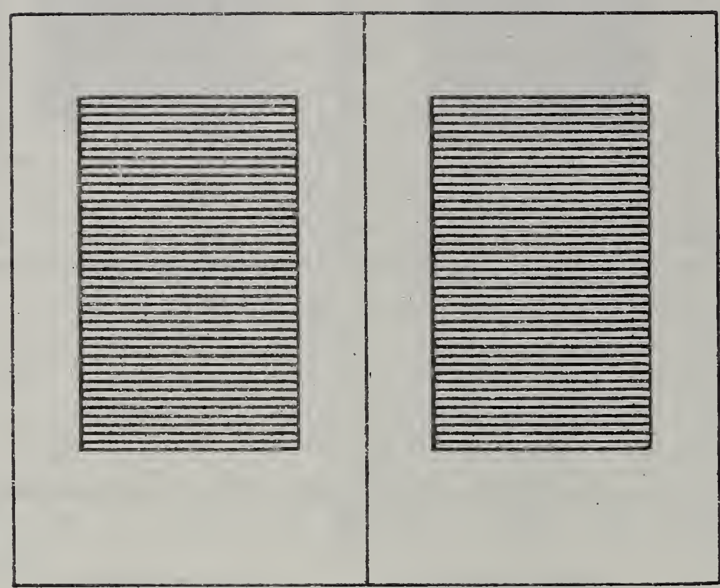


Fig. 3. Appearance of book with page format based on Golden Section proportions, but having inner and outer margins equal. Compare with Fig. 2, in which the inner and outer margins are in the ratio G.

Another configuration, which will not be depicted or discussed further in the analysis here, has become increasingly popular in recent years in books that are specially designed to have strong visual impact. In this arrangement, the layouts of the left and right pages, instead of being mirror images of each other, are identical in form, usually with the wide margins (often exceptionally wide) on the left on both pages. One recent book on legibility and typographic design, Spencer's The Visible Word (1969), is printed in this style.

The first decision to be made in applying the Golden Section to page design is whether the G proportion should be applied to the separate single pages, or to the full double page that the book reader normally has in front of him (as shown in Figs. 2 and 3). Some quick sketches showed that a double-page aspect ratio of G results in unappealing single-page proportions, at least for me, so if I am relatively typical, it seems that the reader's attention is really focussed on one page at a time and he receives little impression of the overall double-page area. The single pages in Figs. 2 and 3 therefore have length/width ratios of G.

The following description will apply to the upper right or lower left page in Fig. 2, the two being identical (wide margin on the left, as is common for single-page documents such as letters). The text area, like the page, also has an aspect ratio of G. The dimensions of the page are G times those of the text area. The lower margin is G times the upper margin, and the left margin is G times the right margin. These requirements fully determine the configuration. As a kind of bonus, it turns out that, in addition, the left and top margins are equal; the height of the text area is equal to the width of the page; the width of the text area is G times the bottom margin; and the secondary diagonal (lower left to upper right) of the text area lies precisely on the secondary diagonal of the page. (The primary diagonals are not aligned.) Possibly there are other bonus equalities or G-ratios present in the design.

b. Use Fraction; Hybrid Page

For the pages of Fig. 2, the use fraction -- the percentage of the page area occupied by text -- is $1/G^2$ [$= 1/(1 + G)$] = 38%. Tinker (1965, p. 182) asserts that printers' style manuals frequently specify a 50% use fraction as the traditional standard, and examination of a few technical books kept at hand by the present author suggests that recent practice has tended toward even higher use fractions. Clearly, this super-esthetic "G" page is not economical and hence not suited for general-purpose use. It might be nice for printing poetry or other limited-edition, art-type books. A more practical page could be produced by making the dimensions of the text area a larger fraction of the dimensions of the page; most of the other G-proportions could be retained. When, as is the case here, the text area and page have the same shape, with the page $\underline{k}$ times the linear size of the text, the use fraction is $1/k^2$. Thus a use fraction of 50% can be achieved by making the text-area dimensions $1/\sqrt{2}$ (≈ 0.71) times the page dimensions, instead of the $1/G$ (≈ 0.62) characterizing the pages in Figs. 2 and 3.

Such a page is shown in Fig. 4. Although all the margins are smaller than the corresponding ones in Fig. 2, the top-to-bottom and inner-to-outer margin ratios are still equal to G. The top margin is still equal to the inner margin. The alignment of one diagonal of each text area and the corresponding page is still present. Some of the relationships have changed, of course: the text length here exceeds the width of the page, and the ratio of the text width to the bottom margin is now considerably greater than G. (It equals $1 + \sqrt{2}$, approximately 2.41.)

c. Five Basic Parameters

Five degrees of freedom exist in the design of a relative page configuration; that is, a set of proportions not tied to a particular absolute size, which would comprise a sixth degree of freedom. In the approach taken here, four of the basic parameters are the page aspect ratio, the text-area aspect ratio, the ratio of the bottom margin to the top margin, and the ratio of the left margin to the right margin (or the outer margin to the inner margin). The fifth parameter can be taken either as the ratio of the page width to the text width, or as the use fraction; either one determines the other, once the first four parameters are chosen. In order to keep all the ratios in the larger-to-smaller direction, it is convenient to work not with the use fraction, but with its reciprocal: the area ratio of page to text. The "ideal" Golden-Section page, shown in Fig. 2, has all five parameters equal to G (or, if the area ratio is used as the fifth parameter, that value is G^2).

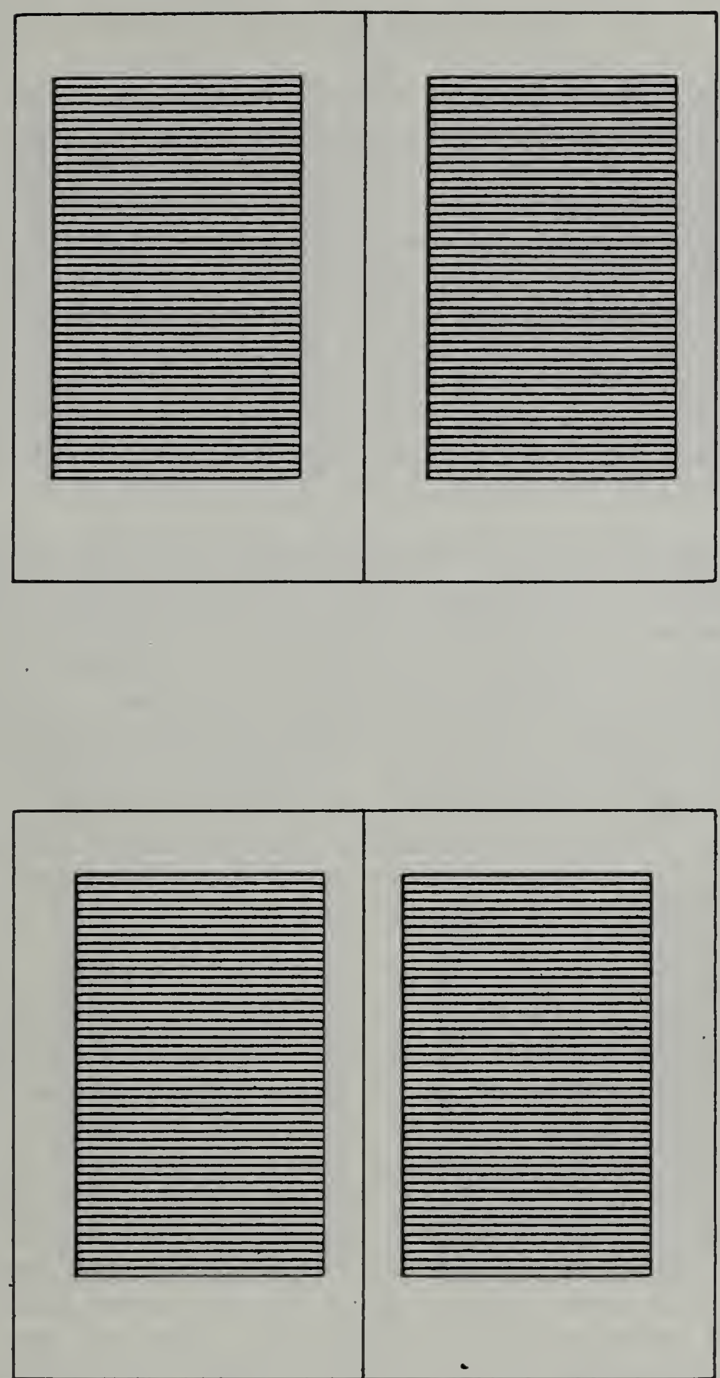


Fig. 4. Appearance of books with a "hybrid" page design. Most of the proportions are still equal to G, as in Fig. 2, but here the dimensions of the text area have been increased so that the page is only $\sqrt{2}$ (1.41) times the linear size of the text area, instead of G (1.62) times. The fraction of the page area printed with text is 50% here, in contrast with the 38% characterizing the pure "G" page of Fig. 2.

d. Pages Based on the $\sqrt{2}$ Ratio

It is intuitively reasonable that a configuration in which many of the ratios among the principle elements are equal to each other should be pleasing, regardless of what the value of the constant ratio is. It therefore appears worthwhile to examine a page design having the five basic parameters equal to some value other than G. We have already noted that a page-to-text width ratio of $\sqrt{2}$ is desirable because it corresponds to an area ratio of 2; that is, the classical typographer's use fraction of 50%. Thus the obvious first choice for the constant value of the five parameters is $\sqrt{2}$. The ideal "$\sqrt{2}$" page is shown in Fig. 5, in both the inner-margin-larger (top) and outer-margin-larger (bottom) arrangements. Fig. 6 shows the arrangement of equal inner and outer margins.

As we have noted earlier, the experimental investigations of observer preferences in rectangle aspect ratios found broad maxima in the preference curve, so that the reduction in preference for a ratio of $\sqrt{2}$ (about 1.41) as compared to a ratio of G (about 1.62), although substantial, cannot be regarded as extreme. An important practical factor in favor of the $\sqrt{2}$ aspect ratio is that it is one of the world's widely used page shapes -- namely, it is the standard of the ISO (International Organization for Standardization). The aspect ratio for 8 1/2 x 11" paper (commercial letter size) is 1.29, and for 8 x 10 1/2" paper (government letter size) is 1.31, both considerably further from the 1.62 ideal than is 1.41.

In analyzing the ideal "G" page, we found that by choosing the five determining parameters equal to G, four bonus "symmetries" (that is, equalities, alignments, or additional G ratios) emerged. It can be shown algebraically that three of these four bonuses are characteristic of any page with the five basic parameters equal; only one bonus depends on the unique properties of the particular value G. Thus the ideal "$\sqrt{2}$" page (Fig. 5), like the ideal "G" page (Fig. 2), has its top margin equal to the wider side margin, the height of the text area equal to the width of the page, and one diagonal of the text area aligned with the corresponding diagonal of the page. The symmetry lost is that the ratio of the width of the text to the bottom margin is G in the "G" page, but is not $\sqrt{2}$ in the "$\sqrt{2}$" page. (It is in fact equal to $1.5 + \sqrt{2}$.) The high value of this ratio in the "$\sqrt{2}$" page (Fig. 5) reflects the favorable fact that the margins are no longer luxuriously huge, as they are in the "G" page (Fig. 2).

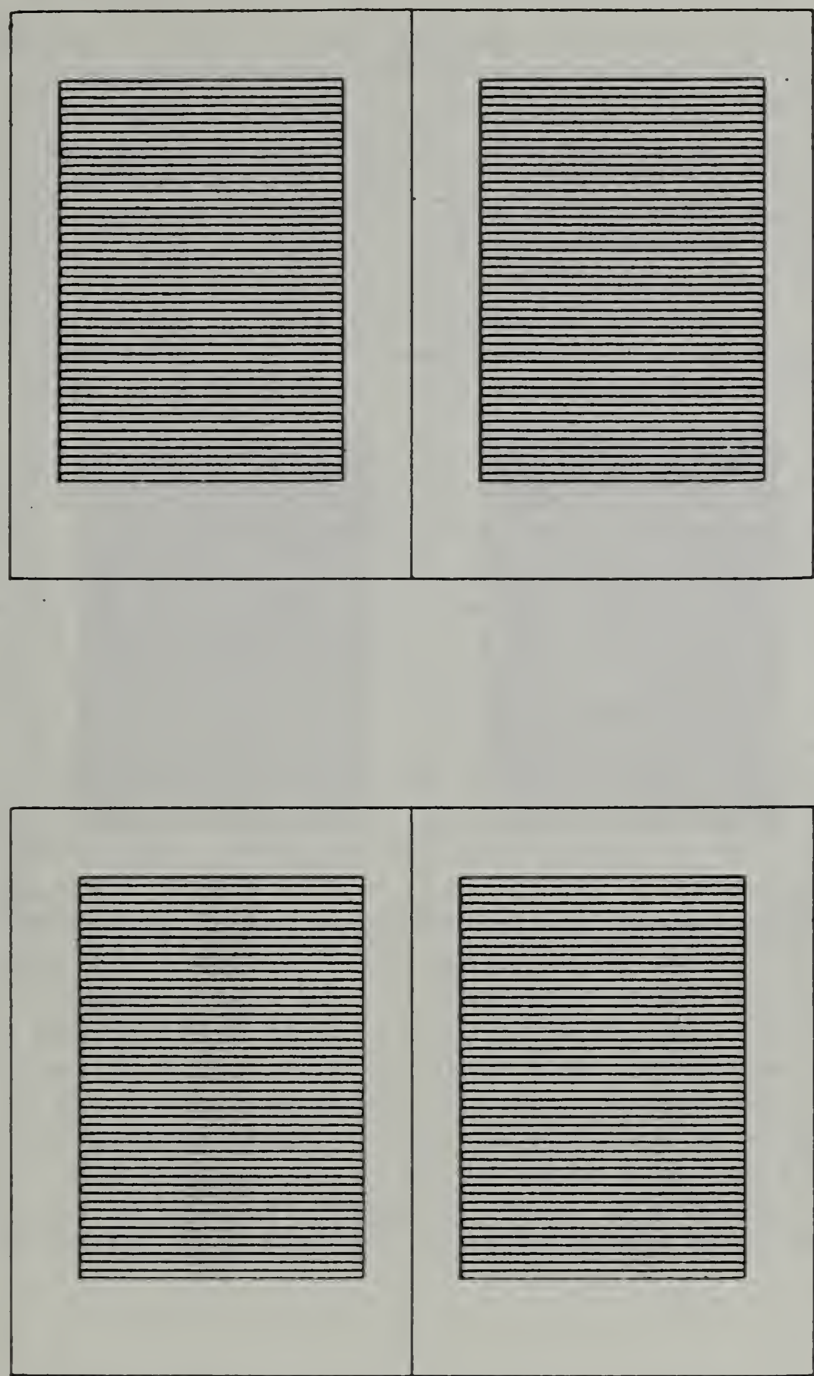


Fig. 5. Appearance of books having ideal "$\sqrt{2}$" pages. This design is analogous to that of Fig. 2, in that all the basic proportions of the page configuration are equal to each other in this figure, as they are in Fig. 2; but here the constant value is $\sqrt{2}$ instead of the value G characterizing Fig. 2. The aspect ratio, $\sqrt{2}$, of the pages shown here corresponds to the shape of ISO paper. The text area covers 50% of the page.

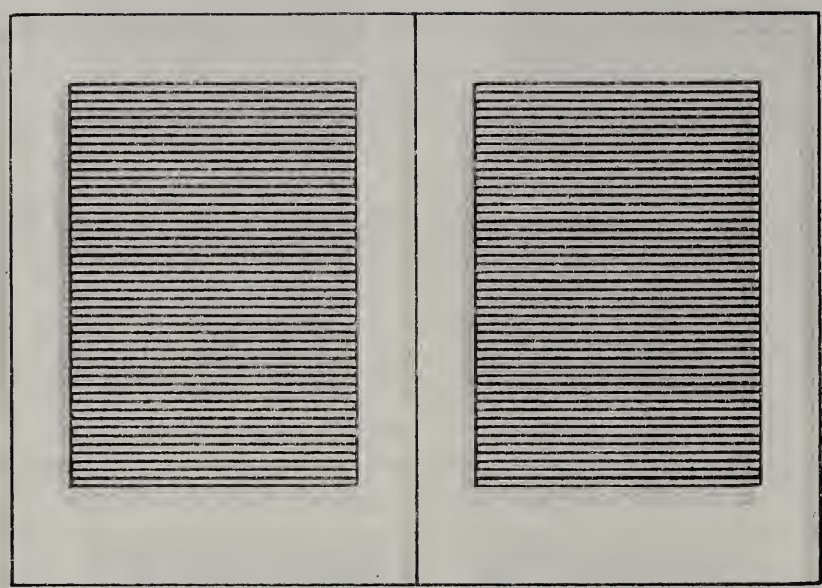


Fig. 6. Appearance of book with page format based on $\sqrt{2}$ proportions, but having inner and outer margins equal. Compare with Fig. 5, in which the inner and outer margins are in the ratio $\sqrt{2}$.

The number $\sqrt{2}$, like G, has special properties of its own, so the "$\sqrt{2}$" page has several "symmetries" missing in the "G" page. Of these, the one with the most striking consequences is that the width of the page is $\sqrt{2}$ times half of the length. The result is the unique property that cutting ISO or other "$\sqrt{2}$" pages in half by bisecting the long sides results in smaller pages of the same shape as the original page ($\sqrt{2}$ aspect ratio). A second "symmetry" that can be seen in Fig. 5 (or 6) is that in ideal "$\sqrt{2}$" pages, the width of the text is exactly equal to half the length of the page.

5.3. Absolute Page Sizes; Proposed New Series

Having been led to the ISO aspect ratio of $\sqrt{2}$ by a demand for a use fraction of 50% combined with the esthetic appeal of a text area with the same aspect ratio as the page, a desirable final step would be fixing an absolute size for the page on some rational basis. Such a basis exists in the finding, represented in Fig. 1, that with the optimal larger sizes of type, line widths should not exceed 5 1/2 inches (33 picas) or reading speed will suffer. To avoid wasting paper, we want to have a line width as close to the 5 1/2-inch maximum as possible. As we have just seen, in a page with the proportions of Fig. 5, the length of the page is exactly double the line (text-area) width, so a choice of a 5 1/2-inch line requires paper 11 inches long. Fortunately, this length is the same as is now used in commercial letter size, so no filing or handling problems arise as they do with the current ISO letter-size length of 11 3/4 inches. Since standard sizes should be expressed in SI units, it seemed better to specify the page length as a conveniently round number of millimeters. A choice of 280 mm. (= 11.02 in.) was explored, and a quite remarkable pattern emerged when the other absolute page dimensions were calculated: <u>every</u> one of the basic dimensions of page and text area came out, when rounded to the nearest tenth of a millimeter, to an integral number of millimeters. The figures are given in Table 1 on the following page. Presumably, the integral-millimeters result is a happy coincidence, but a number mystic like Pythagoras would surely have regarded it as a sign.

TABLE 1. Proposed New Standard Letter Size and Ideal Page Configuration

Item	Millimeters (Nearest tenth)	Inches (Nearest 1/16)
Page length	280.0	11
Page width	198.0	7 13/16
Text length	198.0	7 13/16
Text width	140.0	5 1/2
Bottom margin	48.0	1 7/8
Top Margin	34.0	1 5/16
Larger side margin	34.0	1 5/16
Smaller side margin	24.0	15/16

Since the page width is only 3/16 in. short of 8 in., the proposed page in essence combines the width of government letter size with the length of commercial letter size. From the point of view of minimizing economic disruption, in terms of changes in both paper-handling machinery and storage containers (filing folders and cabinets), the proposed size of 7 3/4 by 11 in. (to the nearest eighth inch) would seem clearly superior to the current ISO letter size of 8 1/4 by 11 3/4. Not only the extra length, but also the extra width of the ISO size is a drawback, since it must result in either lines of print too long for optimum reading speed, or wastefully wide side margins (1 3/8 inches each, on the average, as compared to 1 1/8 inches in the configuration proposed here).

To the extent that any size of paper with a $\sqrt{2}$ aspect ratio has a chance of being adopted as a United States standard, the size proposed here would seem to have about the best chance. The remaining obstacle to world standardization would be to convince the ISO to retain their standard shape, but change their standard size. It should be recalled that the absolute size of the ISO letter page is a direct consequence of the choice of the basic sheet size (A0) as having an area of exactly one square meter. The consequence of imposing an irrational (in the mathematical sense) aspect ratio like $\sqrt{2}$ on a simple page area of 1 m^2 is that the linear dimensions of A0 and all the other sizes in the ISO series are not expressible as exact numbers in either the English or the metric system. The exact size of A0 paper, in mm., is: width = $1000/2^{1/4}$, length = $1000 \cdot 2^{1/4}$. To the nearest micrometer, these dimensions are 840.896 by 1189.207 mm.*

What is the advantage of choosing an exact area like one square meter? This basic area is evidently meant to be a reference area for specifying paper weight. The weight of paper can be expressed as the weight of some specified number of sheets, each of area 1 m^2. Thus, if sheets of exactly 1-m^2 area are available, a manufacturer can measure the standard weight of the paper by an actual weighing operation, and no calculation is needed. What happens, however, if the paper he has in hand has an area different from 1 m^2, say A m^2? Then the manufacturer simply performs the standard weighing operation with his actual paper and divides the answer by A to find out how much sheets of area 1 m^2 would have weighed.

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*The smaller sizes in the ISO A series are denoted A1, A2, etc. Each is obtained from the next larger size by dividing the latter in half parallel to the short edges. All sizes in the series retain an aspect ratio of $\sqrt{2}$. The length, width, and area of the paper size An are expressible exactly as:

$$\ell_{An} = \frac{1000}{(\sqrt{2})^n} \times 2^{1/4}, \quad w_{An} = \frac{1000}{(\sqrt{2})^n} / 2^{1/4}, \quad a_{An} = \frac{1}{2^n},$$

the length and width being given in mm. and the area in m^2.

I have no information as to what fraction of the time in actual practice in ISO countries the paper weighed is of area 1 m^2. It certainly does not seem that doing one division is a very heavy price to pay for being able to deal with sheets of convenient size, say letter (A4) size. The point of this argument is that weights of paper could easily enough be referred to a standard basis of 1-m^2 area regardless of what the standard sizes of paper might be. By imposing the not very helpful requirement that one member of the standard series of paper sizes actually have an area of 1 m^2, the ISO has to pay the price of an awkwardly large letter size, and irrational linear dimensions for all sizes. (The latter characteristic violates the mathematician's esthetic desire for maximum simplicity; it is not of much practical consequence, since paper sizes are most often specified only to the nearest whole millimeter, anyway.)

Because the length-to-width ratio of "$\sqrt{2}$" paper is an irrational number, it is impossible for both the length and width to be simultaneously expressible as exact (rational) numbers, regardless of the absolute size; but there is no reason why one of the two dimensions cannot be exact. In fact, the ISO B series of sizes, intermediate to the A sizes, does have one exact dimension*. For our proposed new letter size, we can define a new A4 paper (which will be denoted A4') with a length of <u>exactly</u> 280 mm. The width would then be $280/\sqrt{2} = 197.990$ mm., which is within 10 μm of being 198 mm.

The dimensions of the new A0' paper would then be 1120 (exact) by $1120/\sqrt{2} = 791.960$ mm. The width is within 40 μm (a bit more than 1 1/2 thousandths of an inch) of 792 mm. The area of the A0' sheet is then $1120^2/\sqrt{2} = 886{,}995$ $mm^2 = 0.887$ m^2, to an accuracy of 5.6 parts per million. Thus, after weighing a package of A0' paper, the manufacturer need only divide by 0.887 -- or multiply by 1.1274 -- in order to convert the weight to a basis of 1 m^2.

While I do believe that the proposed A4' letter size is somewhat more convenient and economical than the existing ISO A4 size, I have not looked into the relative merits of the A and A' series for the other sizes of interest. Anyone who takes this proposal seriously enough to want to explore such comparisons may be aided by Table 2, which contrasts the A and A' series size by size.

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*The basic size B0 is defined as having a width of exactly 1000 mm. and a length of $1000 \times \sqrt{2}$ mm. The successively smaller sizes B1, B2, etc. are, like the A sizes, obtained by halving, with preservation of the $\sqrt{2}$ aspect ratio. The size Bn has linear dimensions that are the geometric means of the corresponding dimensions of sizes An and A(n-1). Thus, in that sense, Bn is precisely intermediate to An and the next larger size, A(n-1). The exact expressions for the dimensions of Bn paper are:

$$\ell_{Bn} = \frac{1000}{(\sqrt{2})^n} \times \sqrt{2}, \quad w_{Bn} = \frac{1000}{(\sqrt{2})^n}, \quad a_{Bn} = \frac{\sqrt{2}}{2^n},$$

the length and width being given in mm., and the area in m^2. Note that, depending on whether <u>n</u> is even or odd, either the width or the length, respectively, has the rational value $1000/2^k$, <u>k</u> integral (the sequence being 1000, 500, 250, 125, etc.).

TABLE 2. Comparison of Current ISO and Proposed New Series of Paper Sizes.

	ISO[a]				Proposed			
	Millimeters, nearest 0.01		Inches, nearest 1/8		Millimeters, nearest 0.01		Inches, nearest 1/8	
Size	Width	Length	Width	Length	Width	Length	Width	Length
4A 0	1681.79	2378.41	66 1/4	93 5/8	1583.92	2240.00	62 3/8	88 1/4
2A 0	1189.21	1681.79	46 7/8	66 1/4	1120.00	1583.92	44 1/8	62 3/8
A 0	840.90	1189.21	33 1/8	46 7/8	791.96	1120.00	31 1/8	44 1/8
A 1	594.60	840.90	23 3/8	33 1/8	560.00	791.96	22	31 1/8
A 2	420.45	594.60	16 1/2	23 3/8	395.98	560.00	15 5/8	22
A 3	297.30	420.45	11 3/4	16 1/2	280.00	395.98	11	15 5/8
A 4	210.22	297.30	8 1/4	11 3/4	197.99	280.00	7 3/4	11
A 5	148.65	210.22	5 7/8	8 1/4	140.00	197.99	5 1/2	7 3/4
A 6	105.11	148.65	4 1/8	5 7/8	99.00	140.00	3 7/8	5 1/2
A 7	74.33	105.11	2 7/8	4 1/8	70.00	99.00	2 3/4	3 7/8
A 8	52.56	74.33	2 1/8	2 7/8	49.50	70.00	2	2 3/4
A 9	37.16	52.56	1 1/2	2 1/8	35.00	49.50	1 3/8	2
A10	26.28	37.16	1	1 1/2	24.75	35.00	1	1 3/8
A11	18.58	26.28	3/4	1	17.50	24.75	3/4	1
A12	13.14	18.58	1/2	3/4	12.37	17.50	1/2	3/4
A13	9.29	13.14	3/8	1/2	8.75	12.37	3/8	1/2

[a]The metric sizes listed were calculated directly from the mathematical definition of the ISO A series of sizes, as given in the footnote on p. 41. They do not necessarily correspond precisely with any official ISO specification of the sizes.

Exact definitions of the length, width, and area of An' paper can be stated as:

$$\ell_{An'} = \frac{1120}{(\sqrt{2})^n}, \qquad w_{An'} = \frac{1120}{(\sqrt{2})^n} / \sqrt{2}, \qquad a_{An'} = \frac{1.2544}{2^n} / \sqrt{2},$$

the length and width being given in mm., and the area in m^2. (The constant with four decimal places in the expression for the area is exact.) Note that, depending on whether n is even or odd, either the length or the width, respectively, has the rational value $1120/2^k$, k integral (the sequence being 1120, 560, 280, 140, etc.).

It is important that it be clearly understood in what spirit the proposal for the new series of sizes is being made. I have tried to show that if a new letter-size page were being designed from scratch with an eye to world-wide adoption, the 198 x 280 mm. size has some appealing aspects. There are, however, several different letter-size pages already in widespread use in the world, and associated with these are extensive current investments in paper-producing and paper-handling machinery, as well as in inventories of paper sheets and ancillary paper products such as envelopes, file folders, etc. These potential conversion losses, as well as all other factors affecting the total cost of preparing, processing, storing, and reading communications that use paper, will necessarily play a major role in considerations of possible size changes within the U.S. government, U.S. industry, and the world as a whole. The economic considerations are different in these three cases, and consistent decisions are not necessarily to be expected. I have not concerned myself in this report, except on an intuitive level, with detailed analysis of the economic, political, or even the human motor performance factors that will rightfully be entered into the balance in making standardization decisions at the three levels that have been mentioned. The proposed A' series of paper sizes is put forward for consideration as one candidate among all the others.

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

There have been a few minor studies concerned specifically with the legibility of typewritten material, but considering the total fraction of all reading material in both government and private industry that is in typed form, an extensive program of research in this area seems easily justifiable economically. In the recommendations that follow, the major emphasis will be on attempting to apply the general findings discussed in section 4 to the specific case of typewritten text.

6.1. Type Style

In general, any familiar, ordinary type face has full speed-of-reading legibility. All capitals, although more visible in isolation than ordinary print, seriously slow continuous reading and should be avoided as much as possible. The government, and other heavy users of computer output, should consider changing over to upper-and-lower-case printing chains as soon as budgets permit.

Italics somewhat retard reading and should be used sparingly. Sans-serif faces and boldface, although fully legible, should not be used for general purposes because of reader preferences.

It is a fairly safe general principle in the field of legibility that any typographical arrangement that is not extremely familiar to the reader will be less pleasing to him, and will be thought by him to be less legible, than the most familiar arrangement. Moreover, if the arrangement is more than a little unfamiliar, it will quite likely actually retard reading speed. Thus, for typewritten material, decorative faces such as manuscript or cursive type are very probably inferior in legibility and to be avoided, and sans-serif faces should be used only for special jobs because readers do not like them as well as traditional serifed styles. "Proportionally" spaced faces (having varying letter widths, as in printing type) are apparently superior in legibility to ordinary one-letter-width styles. It would seem warranted for the government to carry out reading-speed studies to confirm this finding and if proportional spacing is indeed superior, to consider specifying that all typewriters procured for routine government use in the future have a proportionally spaced type face. Some consideration will have to be given to the negative factor that with varying letter widths, neat correction of some errors will require more extensive retyping than would be necessary when all characters occupy the same lateral space.

6.2. Type Size and Leading

The most legible of all standard type sizes apparently is 11 point, although 10-point and 12-point sizes are very nearly as good. Readers also like 11-point type best. In terms of familiar reading matter, these optimum sizes are on the large side, but are not unusually large. Small print (6- to 8-point, or smaller), such as is commonly found in newspapers and book footnotes, slows down reading and is not good for mass, general-purpose usage. About two points of leading (extra space between lines) is best for any type size ordinarily used.

The familiar typewriter sizes, pica and elite, are close to optimum in size, and no change is needed. Elite type has a letter height resembling 11-point type, but has a line spacing of 12 points (single spaced), so that visually it is like 11-point type with one point of leading. This configuration is essentially optimal, although tests would be desirable to determine whether a line spacing of 13 points might not be slightly superior. Pica type is visually like 12-point type set solid and should not be much inferior to elite, but again tests are desirable. The trend over the years away from pica and toward elite might partly be a matter of economics -- fitting more print on a page -- but there might well also be a preference by readers for the smaller size and possibly an actual reading-performance benefit.

6.3. Line Width, Margins, and Column Arrangement

For any of the ordinary sizes of type (6- to 12-point), printed with at least a point or two of leading, the range of line widths yielding maximum reading speed can be stated as about 23 $\pm$ 5 picas. For 11- and 12-point type only (the optimum sizes, and the usual sizes for typewriting), the range is a bit higher and broader: 25 $\pm$ 8. Since a pica is one-sixth of an inch, a 17-pica line is only about 2 7/8 inches, and a 33-pica line is still only about 5 1/2 inches.

According to the existing evidence, margins do not contribute to legibility but serve only esthetic and convenience functions (allowing for marginal notes, keeping wear caused by handling from encroaching on the text, etc.) Even with one-inch margins on both the left and right, the ideal width of a piece of paper containing single-column print is from roughly 5 to 7 1/2 inches. Thus, narrower typing paper than is currently popular would serve just as well from the point of view of reading performance. Paper 8 or 8 1/2 inches wide either has unnecessarily large margins or the line of print is too long and retards reading speed.

Readers prefer a two-column layout in books to a single-column arrangement. With justified printing (even right margin), only one pica between columns is necessary for a visual barrier. Justification does not improve reading performance, so ordinary unjustified typewriting is at no disadvantage. However, it seems likely that several picas of separation, or a printed rule, would be desirable for two-column unjustified printing.

One way of making full use of a piece of typing paper 8 or 8 1/2 inches wide would be to type in two-column style. For example, on an 8 1/2-inch sheet, 7 3/4 inches could be filled with print without retarding reading speed by having two columns each 3 7/8 inches wide, with 1/4-inch margins on both sides and between the columns. On paper 8 inches wide, the width of each column could be 3 5/8 inches, for a total of 7 1/4 inches of print. Short letters in this format would be typed entirely on the left half of the page, a novel but not necessarily ugly arrangement. For longer letters, the typist would have to roll the page back up to the top to begin the second column, but an electric typewriter equipped with a reversible line-feed key would facilitate the process. This idea might be worth exploring if current U.S. government and commercial letter sizes are retained in the future. The increased number of carriage returns associated with such short lines would presumably result in a longer total typing time, and this loss would have to be weighed against the potential savings of reading time for all the readers in the development of an overall estimate of the net cost of preparing letters in this manner.

As an alternative to two-column, narrow-margin typing, a long, thin page size could be used for single-column typing. A sheet 7 inches wide would allow for the maximum safe line width of 5 1/2 inches, with 3/4-inch margins on both sides. A familiar and convenient length for the page would be 11 inches. The aspect ratio (11/7 = 1.571) of such a page is much closer to the "Golden-Section" esthetic ideal of 1.618 (see section 6.7 of this summary) than is the ratio for 8 1/2 x 11" paper (1.294), 8 x 10 1/2" paper (1.312), or ISO paper (1.414). Despite the visually pleasing narrow profile of a 7 x 11" sheet, and the concomitant savings of paper, there are reasons, summarized in sections 6.7 and 6.8, for considering a size of 7 3/4 x 11" more practical as a possible standard. The extra width would allow for side margins averaging 1 1/8 inches each.

6.4. Page Length

The length of a page affects reading speed only in secondary ways. Printing a given text of substantial length on very short pages causes delays for page turning and visually locating the first word on the new page. Printing on very long pages causes either delays for pushing the page up several times or, if the pages are not moved, delays due to the reduced visibility of the print at the top and/or bottom of the page (depending on the position of the reader's head). Experiments to find the optimum page length (for type set with all other typographical factors optimum) would be helpful, but very extensive test materials, dozens of pages long, would presumably be necessary to allow the differences in overall reading speed to show up.

In the absence of such experimental information, page length should be determined by esthetic considerations, ease of handling and filing, and the economics of paper manufacture and handling by machines.

6.5. Paragraphing

The experimental evidence seems to suggest that making every sentence or two a separate paragraph allows for reading speeds higher than when the same material is set in much longer paragraphs. In the experiment that led to this conclusion, paragraphs were indicated by the customary indentation of the left margin. The current government typing format indicates new paragraphs by skipping lines only, with no indentation. An experiment seems called for to find out whether the flush-left-margin arrangement retards reading speed relative to the older, indented arrangement. If it does, a reversion to the old style within the government might be worthwhile, despite the tiny saving of paper and the possible esthetic superiority of the new style.

6.6. Positioning of Paper

The position of a printed page that leads to most rapid reading is with the page perpendicular to the "line of sight" from the bridge of the reader's nose to the center of the text area, and the lines of print visually horizontal. The characteristic downward tilt of the head of the average reader requires that the page be tilted with the top edge back about 45° from the vertical. Reading horizontal copy (90° back from the vertical), as with the page lying flat on a desk, materially slows reading. The government, and private industry as well, should therefore consider acquiring desks containing a section that can be tilted up at the required 45° angle, or at least making available to employees separate book racks that accomplish the same purpose.

The way paper emerges from a typewriter during typing probably puts the page at a nearly optimum angle relative to the line of vision of the typist, but provision should be made for the rough draft from which the text is being copied to be held at a similar angle (as on a rack) as close to the typewriter as possible. Many typists now keep the rough draft flat and off to one side, a position that may cause reading inefficiency due to non-optimal rotation or tilt in one to all three of the relevant directions.

6.7. Esthetics and Page Proportions

Since ancient times, it has been believed by some that the most pleasing rectangle is one such that the aspect ratio -- the ratio of the length to the width -- is equal to the ratio of the sum of the length and width to the length. This ideal proportion, called the Golden Section (G), is equal to $(1 + \sqrt{5})/2$, approximately 1.618. Experimental studies of preference have confirmed that rectangles with an aspect ratio in the neighborhood of G are considered most pleasing, but the peak of preference is not sharp, and is not unequivocally centered precisely at the value G.

With the portion of a page on which the print is located regarded as a rectangle within the rectangle of the page itself, the basic design of a page reduces to selecting aspect ratios for the inner and outer rectangles, choosing the relative sizes of the rectangles, and locating the inner rectangle within the outer. A "super-esthetic" page was designed (Fig. 2) in which both the page and text area have aspect ratios of G, the page is linearly G times the size of the text area, the lower margin is G times the upper margin, and one side margin is G times the other.

When the page and text area have the same proportions, and the page dimensions are $\underline{k}$ times those of the text area, the fraction of the page area devoted to the text is $1/k^2$, and for the ideal Golden-Section page, this "use fraction" is only 38%. The traditional use fraction regarded as a good compromise between esthetics and practicality is 50%, and to achieve that fraction, $\underline{k}$ has to be $\sqrt{2}$, approximately 1.414. A page was therefore designed (Fig. 5) having all the basic ratios equal to $\sqrt{2}$ instead of G.

Although a ratio of $\sqrt{2}$ is noticeably less pleasing than a ratio of G to the average observer, it is closer to G than are the aspect ratios characterizing current U.S. government and commercial letter sizes (see section 6.3 above), and has the strong practical advantage of being the aspect ratio associated with a widely accepted page shape, the ISO standard now popular in many countries other than the U.S.A. Paper of this shape has the unique property of preserving the aspect ratio upon halving, and each ISO size is just half of the next larger size, so there is no waste at all when any ISO page is cut up into smaller sizes.

6.8. Absolute Page Dimensions; Recommendation

The aspect ratio of a page is only a relative measure. The absolute size of the page is of at least equal importance, and is determined not only by esthetics, but by considerations of legibility, ease of handling, savings on paper, the structure of existing machinery for paper manufacture and handling, and the costs of paper storage. Arguments have been presented in this report (section 5.3) in favor of a letter size with ISO proportions ($\sqrt{2}:1$), but with absolute dimensions equal to 198 x 280 mm. (7 3/4 x 11 in.). Since the width of the proposed sheet is only a little less than that of government letter size, and the length is equal to that of commercial letter size, it represents a kind of compromise that might ease acceptance within this country. The present ISO letter size (designated A4) is wider than necessary (8 1/4 in.); with a line width of 5 1/2 in. -- the greatest permitting maximum speed of reading -- the side margins average a wasteful 1 3/8 in. each. The ISO paper is also too long (11 3/4 in.), in terms of what we are now used to in handling and filing in the U.S.A.

If the entire world is to settle on a single standard, and if the proposed 7 3/4 x 11 in. size is acceptable in this country, the ISO could be requested to reconsider the absolute scale (but not the shape) of its present A series of sizes. (The details of the proposed replacement series, A', are given in Table 2 in section 5.3.) Despite its rather complicated derivation, the A' series proposed here is actually nothing more than the ISO A sizes contracted linearly by approximately 6 percent. Arguments have been presented in this report to indicate that the <u>absolute</u> level of the present ISO size scale is based on a mathematical simplification with limited utility, rather than on significant usage factors.

This report has not dealt in any technical detail with problems of economic impact or the mechanics of paper manufacture and handling. These factors will inevitably exert major influences in any negotiations that may arise concerning U. S. national standard or world standard paper sizes. The new series of sizes proposed here is offered as a candidate to be weighed against the several alternative possibilities by those in possession of <u>all</u> the relevant information.

Since the economies of all industrialized nations should continue to trend toward expansion for the foreseeable future, the absolute cost of converting to new paper sizes will grow every year. Since the U.S.A. and the large bloc of countries using ISO paper sizes are not now on the same standard, one group or the other -- or both, if a wholly new series of sizes is chosen -- will necessarily face significant conversion costs, regardless of what world standard might be chosen. It is conceivable that the absolute level of cost may already be too high for one or both of us, weighed against the benefits expected. If negotiations are ever to be undertaken on a universal standardization of paper sizes, now would seem to be the time.

7. REFERENCES

Baudin, F. (1967). Book review: Miles A. Tinker, _Bases for Effective Reading_. Minneapolis: University of Minnesota Press, 1965. _J. typog. Res_. _1_, 204.

Becker, D., Heinrich, J., Sichowsky, R.v., and Wendt, D. (1970). Reader preferences for typeface and leading. _J. typog. Res._ _4_, 61.

Bedford, A. V. (1950). Mixed highs in color television. _Proc. I.R.E_. _38_, 1003.

Bitterman, M. E. (1945). Heart rate and frequency of blinking as indices of visual efficiency. _J. exp. Psychol_. _35_, 279.

Bitterman, M. E., and Soloway, E. (1946a). The relation between frequency of blinking and effort expended in mental work. _J. exp. Psychol_. _36_, 134.

Bitterman, M. E., and Soloway, E. (1946b). Minor studies from the Psychological Laboratory of Cornell University, XCIII. Frequency of blinking as a measure of visual efficiency: some methodological considerations. _Am. J. Psychol_. _59_, 676.

Carmichael, L., and Dearborn, W. F. (1947). _Reading and visual fatigue_. Houghton Mifflin, Boston.

Davenport, J. S., and Smith, S. A. (1965). Effects of hyphenation, justification, and type size on readability. _Journalism Quarterly_ _42_, 382.

Dearborn, W. F. (1906). The psychology of reading: an experimental study of the reading pauses and movements of the eye. _Arch. Phil., Psychol. and sci. Methods_, (no vol. no.), No. 4. Also classified as _Columbia U. Contributs. to Phil. and Psychol_. _14_, No. 1, Science Press, New York (Monograph).

Dockeray, F. C. (1910). The span of vision in reading and the legibility of letters. _J. educ. Psychol_. _1_, 123.

Engel-Hardt, R. (1922). _Der goldene Schnitt im Buchgewerbe_, 2nd ed. J. Mäser, Leipzig.

Fabrizio, R., Kaplan, I., and Teal, G. (1967). Readability as a function of the straightness of right-hand margins. _J. typog. Res_. _1_, 90.

Fechner, G. T. (1876). _Vorschule der Aesthetik_. Breitkopf and Härtel, Leipzig. Also see 2nd ed., 1897-8.

Foster, J. (1968). Commentary: psychological research into legibility. J. typog. Res. 2, 279.

Hagenmaier, O. (1949). Der goldene Schnitt. W. Tapper, Ulm.

Hoggatt, V. E., Jr. (1969). Fibonacci and Lucas numbers. Houghton Mifflin, Boston.

Luckiesh, M., and Moss, F. K. (1935a). The effect of visual effort upon the heart-rate. J. gen. Psychol. 13, 131.

Luckiesh, M., and Moss, F. K. (1935b). Visibility: its measurement and significance in seeing. J. Frankl. Inst. 220, 431.

Luckiesh, M., and Moss, F. K. (1937). The eyelid reflex as a criterion of ocular fatigue. J. exp. Psychol. 20, 589.

Luckiesh, M., and Moss, F. K. (1938). Effects of leading on readability. J. appl. Psychol. 22, 140.

Luckiesh, M., and Moss, F. K. (1939a). Frequency of blinking as a clinical criterion of ease of seeing. Am. J. Ophthal. 22, 616.

Luckiesh, M., and Moss, F. K. (1939b). The visibility and readability of printed matter. J. appl. Psychol. 23, 645.

Luckiesh, M., and Moss, F. K. (1940a). Boldness as a factor in type-design and typography. J. appl. Psychol. 24, 170.

Luckiesh, M., and Moss, F. K. (1940b). Criteria of readability. J. exp. Psychol. 27, 256.

Luckiesh, M., and Moss, F. K. (1941). The effect of line length on readability. J. appl. Psychol. 25, 67.

McIlwain, K. (1952). Requisite color bandwidth for simultaneous color-television systems. Proc. I.R.E. 40, 909.

Paterson, D.G., and Tinker, M. A. (1931). Studies of typographical factors influencing speed of reading: VI. Black type versus white type. J. appl. Psychol. 15, 241.

Paterson, D. G., and Tinker, M. A. (1932). Studies of typographical factors influencing speed of reading: X. Style of type face. J. appl. Psychol. 16, 605.

Paterson, D. G., and Tinker, M. A. (1938). The part-whole proportion illusion in printing. J. appl. Psychol. 22, 421.

Paterson, D. G., and Tinker, M. A. (1940). How to make type readable. Harper, New York.

Payne, D. E. (1967). Readability of typewritten material: proportional versus standard spacing. J. typog. Res. 1, 125.

Sanford, E. C. (1888). The relative legibility of the small letters. Am. J. Psychol. 1, 402.

Skordahl, D. M. (1958). Effect of sloping text upon the speed of reading and upon visibility. Unpublished paper, University of Minnesota.

Spencer, H. (1969). The visible word, 2nd ed. Hastings House, New York.

Strauss, V. (1967). The printing industry. Printing Industries of America, Washington, D.C., and Bowker, New York.

Tanselle, G. T. (1967). The identification of type faces in bibliographical description. J. typog. Res. 1, 427.

Taylor, C. D. (1934). The relative legibility of black and white print. J. educ. Psychol. 25, 561.

Tinker, M. A. (1932). The influence of form of type on the perception of words. J. appl. Psychol. 16, 167.

Tinker, M. A. (1946). Validity of frequency of blinking as a criterion of readability. J. exp. Psychol. 36, 453.

Tinker, M. A. (1948). Readability of book print and newsprint in terms of blink-rate. J. educ. Psychol. 39, 35.

Tinker, M. A. (1954). Effect of slanted text upon the readability of print. J. educ. Psychol. 45, 287.

Tinker, M. A. (1956a). Effect of sloped text upon the readability of print. Am. J. Optom. & Arch. Am. Acad. Optom. 33, 189.

Tinker, M. A. (1956b). Effect of angular alignment upon readability of print. J. educ. Psychol. 47, 358.

Tinker, M. A. (1957). Effect of curved text upon readability of print. J. appl. Psychol. 41, 218.

Tinker, M. A. (1963). Legibility of print. Iowa State U. Press, Ames, Iowa.

Tinker, M. A. (1965). Bases for effective reading. U. of Minnesota Press, Minneapolis.

Updike, D. B. (1962). Printing types: their history, forms, and use, Vol. 1, 3rd ed. Belknap Press (of Harvard U. Press), Cambridge.

Vorob'ev, N. N. (1963). The Fibonacci numbers. Heath, Boston.

Weintraub, D. J., and Eisenberg, M. (1966). The shape of things to come: Miss America versus the golden rectangle. Am. Psychologist 21, 246.

Weiss, A. P. (1917). The focal variator. J. exp. Psychol. 2, 106.

Wiggins, R. H. (1967). Effects of three typographical variables on speed of reading. J. typog. Res. 1, 5.

Woodworth, R. S. (1938). Experimental psychology. Holt, New York.

Woodworth, R. S., and Schlosberg, H. (1954). Experimental psychology, rev. ed. Holt, New York.

Zachrisson, B. (1965). Studies in the legibility of printed text. Almqvist & Wiksell, Stockholm.